Airborne Information for Lateral Spacing (AILS) Benefit Estimate

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Executive Summary

AIRBORNE INFORMATION FOR LATERAL SPACING DESCRIPTION

The overall goal of NASA's Terminal Area Productivity (TAP) is to safely maintain good weather airport operating capacity during bad weather. Airborne Information for Lateral Spacing (AILS) technology is the component of TAP that enables independent approaches to parallel runways in weather conditions where only dependent (staggered) or single stream approaches are allowed now. Under current FAA regulations, during instrument flight rule (IFR) (bad) weather conditions, independent approaches to parallel runways may be made only if the runway centerlines are separated by 4,300 feet or more. Dependent approaches can be made to runways with centerline separations between 2,500 feet and 4,300 feet. If a precision runway monitor (PRM) radar is available, and both controllers and aircrews are qualified to use it, independent approaches can be made to runways with separations of at least 3,400.[1] Only a single approach stream is allowed with runway separations less than 2,500 feet.

The quality of the displayed information and the controller-pilot response times are considered insufficient, even with PRM, for *controllers* to safely maintain lateral aircraft separations closer than 3,400 feet in instrument conditions. The AILS technologies provide sufficient information to allow *aircrews* to assume responsibility for maintaining safe separations in instrument conditions. NASA Langley Research Center has built and flight tested an AILS system that allows safe independent parallel operations to runways with centerline separations as small as 2,500 feet.

The Logistics Management Institute (LMI), under contract to NASA, has estimated the reduction in arrival delay that can be expected for AILS systems implemented at New York Kennedy (JFK), Detroit Wayne County (DTW), Minneapolis-St. Paul (MSP), and Seattle-Tacoma (SEA). Benefits are based on

[1] This is a nominal figure; the FAA can and has granted waivers to the basic order, permitting PRM approaches for runways slightly closer than 3,400 feet.

the minutes of arrival delay saved by the AILS technologies at these four airports over a 10-year period from 2006 through 2015. The benefits were estimated using detailed airport capacity and delay models for each of the four airports. Benefits were based on the difference between delays with AILS and those from three technology baselines that have been defined in previous NASA TAP analyses. The three baselines include a Current Technology baseline (CT), a Passive Final Approach Spacing Tool baseline (PFAST), and an Active Final Approach Spacing Tool baseline (AFAST). PFAST and AFAST are enhanced variants of NASA's Center TRACON Automation System (CTAS)[2].

AILS BENEFITS

The monetary benefit of AILS is based on the value of the minutes of delay saved by AILS. Two values of cost per minute of delay are used. The lower of the two includes airlines' variable operating costs (VOC) which do not include capital depreciation minus fuel and plus flight attendant (FA) costs. The higher of the two includes direct operating costs (DOC) plus flight attendant costs. The DOC+FA ($46.77 per minute) and VOC-fuel+FA ($25.68 per minute) define upper and lower bounds on the cost of delay. The average of the DOC and VOC costs is used to calculate savings. Table 1 shows the 10-year constant dollar savings for AILS implementation at the four airports studied.

Table 1. Ten-Year AILS Cost Savings (1997 Constant Dollars in Millions) (Based on Average of Variable and Direct Operating Costs per Minute)

Technology Baseline	Total	MSP	DTW	JFK	SEA
Current Technology	554	245	201	18	90
PFAST	470	205	173	17	76
AFAST	267	113	110	12	31

The savings are lower for the more advanced baselines because the basic delay is lower for those technologies.

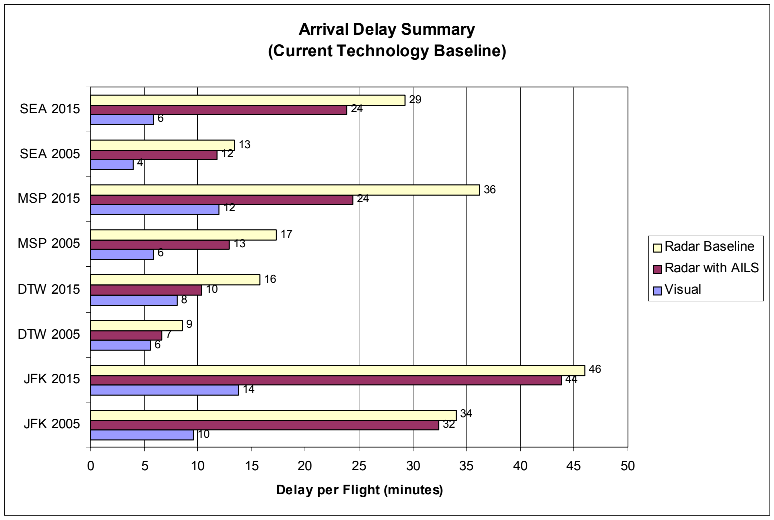
The savings for JFK for all baselines are noticeably low. At JFK the Parallel 4 and Parallel 22 runway configurations that AILS benefits are not frequently used because other configurations have higher capacity. AILS improves the capacity of the runways, but not enough to match the competing configurations

Figure 1 shows the estimated delay per flight for Current Technology Baseline with and without AILS for each of the four airports in 2005 and 2015. The baseline delay is shown for both instrument flight rules (IFR) and visual flight rules

[2] TRACON is an acronym for terminal radar approach control

(VFR). The figure shows how much AILS contributes to the TAP goal of achieving VFR performance in IFR conditions. The figure also shows that AILS provides increasing benefits in future years as demand grows.

Figure 1. Arrival Delay per Flight (Current Technology Baseline)



AILS Costs

The Logistics Management Institute also made a preliminary estimate of AILS costs based on the hardware and software ensemble used in the NASA flight tests. The estimate covered navigation receivers, new wiring, aircrew training, and software for the Traffic Alert and Collision Avoidance System (TCAS) and the Flight Management System (FMS). Assumptions about equipment quantities were based on previous TAP studies and educated guesses. Table 2 shows results of the estimate. The constant dollar estimates are converted to present value (discounted) dollars using a 7 percent discount rate and a 1997 base year.

Table 2. 2005-2016 10-year Lifecycle Cost Summary (In Millions)

Estimated component	Quantity assumptions	1997 Constant dollars	Present value dollars
Multimode Receiver	(1240 aircraft)	45.1	18.4
TCAS-to-FMS Cable	(6200 aircraft)	4.9	2.0
AILS Training	(148,800 training sessions)	11.4	5.6
TCAS Software	(4 vendors)	0.3	0.2
FMS Software	(4 vendors)	0.4	0.2
Total		65.2	27.6

Present value analyses are commonly used to evaluate the economic benefits of investments and returns expended over future years. The Net Present Value (NPV) is the present value of the net cash flows (i.e., discounted benefits minus discounted costs). Table 3 shows the combined benefits for all four airports in constant dollars and present value dollars.

Table 3. AILS BenefitsFor Four Airports

Scenario baseline	Minutes in millions	1997 Constant $ in millions			Present value $ in millions		
		VOC -fuel+FAs	DOC +FAs	Average	VOC -fuel+FAs	DOC +FAs	Average
Current technology	15.3	393	715	554	150	272	211
PFAST	13.0	333	607	470	127	231	179
AFAST	7.4	189	345	267	72	131	102

Table 4 shows the Net Present Values and the benefit-to-cost ratios for AILS. The fact that the net present values for all baselines are positive based on benefits for only 4 airports and costs for a substantial fraction of the commercial fleet suggests that AILS implementation should be economically justifiable.

Table 4. Net Present Values and Benefit-to-Cost Ratios

Baseline scenario	Present value of benefits in millions	Present value of costs in millions	Net present value in millions	Benefit to cost ratio
Current Technology	211	26.4	185	8.0
PFAST	179	26.4	153	6.8
AFAST	102	26.4	76	3.9

SUMMARY

The results of the analyses of four airports support the following conclusions:

- Use of a basic AILS system that allows independent approaches to runways separated by 2,500 feet is estimated to produce significant benefits at Detroit, Seattle, and Minneapolis.

- The modest benefits estimated for New York demonstrate that airport-specific operating conditions affect AILS benefits and must be considered when selecting airports for AILS implementation.

Net Present Values, based on preliminary cost estimates and the 4 airports, indicate that AILS benefits should be adequate to justify implementation.

NASA is developing the Airborne Information for Lateral Spacing (AILS) technology to improve capacity at airports with closely spaced parallel runways. In this task we estimate the benefits of implementing an initial version of the AILS technology at 4 airports: New York Kennedy (JFK), Detroit (DTW), Minneapolis-St. Paul (MSP), and Seattle-Tacoma (SEA). The airports were chosen because they have parallel runways with centerline spacing suitable for the initial AILS technology (i.e., centerline separations of at least 2,500 feet).

The AILS program is part of the broader NASA Terminal Area Productivity (TAP) program whose purpose is to enable good weather airport operating capacities in bad weather. We have, in the past, estimated the benefits of other TAP technologies by determining the reduction in arrival delay that will result from TAP implementation. In this effort we use the same approach and estimate the reductions in arrival delay that will occur through implementation of AILS at the four airports. We use capacity and delay models for each airport to perform the analysis. We modified the JFK and DTW models previously used for TAP and produced new models for MSP and SEA.

The analysis results indicate that AILS benefits at three of the airports studied are on the order of 3 to 9 million dollars per year (in 1997 constant dollars). Benefits are only 1.1-1.5 million dollars per year at the fourth airport, JFK, because the closely spaced parallel runways are infrequently used, and the improved capacity generated by AILS is not enough increase their use. At the three airports showing respectable benefits, the benefits increase proportionally with increased future airport demand.

At NASA's request, we estimated costs for an AILS system based on the hardware and software ensemble being used for the AILS tests and demonstration. Net Present Values and benefit-to-cost ratios based on the estimates indicate that AILS implementation should be economically justified.

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Chapter 1
Overview and Summary Benefits Results

This chapter describes the Airborne Information for Lateral Spacing (AILS) technology, the methods used to estimate its potential benefits, a summary of the results, conclusions and recommendations. Subsequent chapters address individual airport results. Appendix A contains meteorological data. Appendix B contains a detailed description of the Seattle-Tacoma Airport model. Appendix C contains capacity model inputs used in the analysis. Appendix D documents the content and results of a preliminary cost analysis for a basic AILS system including a benefit-to-cost estimate. Appendix E contains charts of arrival capacities and delays that summarize AILS impact. Appendix F lists acronym definitions.

AILS Description

AILS technology is a component of NASA's Terminal Area Productivity (TAP) program. The overall goal of TAP is to safely maintain good weather airport operating capacity during bad weather. AILS specifically is designed to allow independent approaches to parallel runways in weather conditions where only dependent or single approaches are currently allowed. Under current FAA regulations, during instrument flight rule (IFR) weather conditions, independent approaches can be made only to parallel runways with centerline separations of 4,300 feet or more. Dependent (staggered) approaches can be made to runways with centerline separations between 2,500 feet and 4,300 feet. If a precision runway monitor (PRM) radar is available, and both controllers and aircrews are qualified in its use, independent approaches can be made to runways with separations of at least 3,400.[1] Only a single approach stream is allowed for runway separations less than 2,500 feet.

The quality of the displayed information and the controller-pilot response times are considered insufficient, even with PRM, for *controllers* to safely maintain lateral separations closer than 3,400 feet in instrument conditions. The AILS technologies provide sufficient information to allow *aircrews* to assume responsibility for maintaining safe separations in instrument conditions. The required technologies include flight data acquisition equipment such as differential global position satellite (DGPS) receivers integrated with a flight management system (FMS), data link equipment such as automatic dependent surveillance - broadcast (ADS-B), and display enhancements for the primary flight display (PFD), the

[1] This is a nominal figure; the FAA can and has granted waivers to the basic order, permitting PRM approaches for runways slightly closer than 3400 feet.

navigation display (ND) and/or a heads-up guidance display. Required information includes identification of safe flight corridors for all aircraft, timely warnings of deviations from the safe corridors, and guidance for evasive maneuvers.

Analysis Description

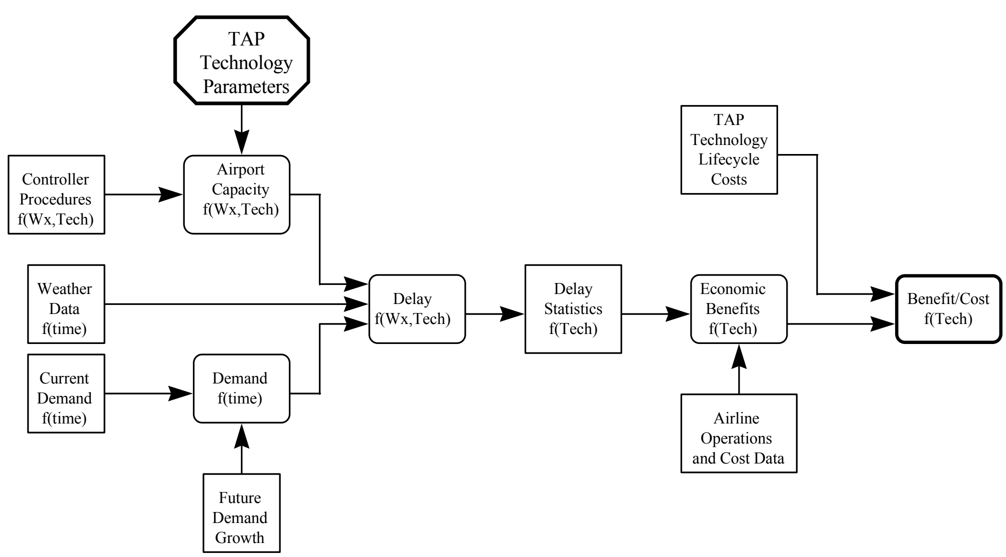
In this study we used the basic analysis method previously developed for analysis of other TAP technologies. (Detailed discussions of the analysis methods, are contained in Reference 1.) Using capacity and delay models for specific airports we estimate the ability of the technology to reduce arrival delays. In this study we estimated the potential impact of AILS at 4 airports: New York Kennedy (JFK), Detroit Wayne County (DTW), Minneapolis-St. Paul (MSP), and Seattle-Tacoma (SEA). New capacity and delay models were produced for MSP and SEA and modifications were made to existing models of JFK and DTW.

Based on NASA input, AILS is assumed to enable independent approaches to parallel runways with centerline spacing of 2,500 feet or more. The 2,500-foot separation is based on the technology being tested by NASA. We note, however, that Reference 1 documents the potential for AILS to support separations as close as 1,200 feet.

Benefits consist of the minutes of arrival delay saved by the AILS technologies at 4 major airports during a 10-year period from 2006 through 2015. For benefit and cost estimating purposes, 2005 is assumed to be the deployment year for the technologies.

Figure 1-1 outlines the analysis approach. This basic approach has not changed from that used for analysis of other TAP technologies.

Figure 1–1. Overview of Analysis Method



AILS benefits were calculated for three technology baselines that were defined in previous TAP analyses. The three include a current technology baseline (CT), a passive final approach spacing tool baseline (PFAST), and an active final approach spacing tool baseline (AFAST). PFAST and AFAST are enhanced variants of the Center TRACON Automation System (CTAS)[2]. The cases analyzed are summarized in Table 1-1.

Table 1-1. 1998 Modeling Scenarios

Title	Baseline	Content	Technology code
Current technology baseline	N/A	Current technology	CT1
Current technology + AILS	CT	AILS	CT2
PFAST baseline	N/A	PFAST	X1
PFAST + AILS	PFAST	PFAST + AILS	X2
AFAST baseline	N/A	AFAST	Y1
AFAST + AILS	AFAST	AFAST + AILS	Y2

The capacity model parameters used to define the baseline technologies are the same ones we used for analysis of the other TAP technologies. Reference 2 contains an extensive discussion of parameters and their values. New aircraft mixes, runway occupancy times, and airport unique inputs were needed for MSP and SEA. The input parameters for all 4 airports modeled in the current analysis are contained in Appendix C.

In this study we developed a new dependent (staggered) arrival model for closely spaced parallel runways. The dependent pair arrival model was not required in previous TAP studies of JFK because the precision runway monitor (PRM) was part of the JFK 2005 TAP baseline, however, analysis of AILS requires a baseline that does not include PRM.

Model Summary

While the details of the capacity and delay models are described in detail in Reference 1, a brief summary is useful for understanding and interpreting the results of the current analysis. We begin with the calculation of capacity for each airport runway configuration as a function of technology and meteorological condition. The result is set of arrival/departure coordinates for each configuration/technology/meteorological condition combination. The capacity curves generated from the coordinates define a trade-off frontier between arrivals and departures.[3] For each technology, one curve is generated for each meteorological condition (typically 4) for each runway configuration (e.g., 13 for JFK).

[2] TRACON is an acronym for terminal radar approach control

[3] The capacity curves are often called *Pareto* curves after the Italian scientist and economist Vilfredo Pareto (1848–1923). A *Pareto Optimality* is a situation where one individual could not be made better off without someone else being made worse off - .i.e. a zero-sum trade-off.

Projected hourly demand is derived from Official Airline Guide (OAG) data and the FAA Terminal Area Forecast (TAF). In some cases the demand is modified based on controller input or tower count data to account for additional general aviation. The base year demand derived from the OAG is inflated by factors derived from the TAF to generate hourly demands for future years. Hourly demand at airports typically varies by season and day of the week. Whenever appropriate, we include separate hourly demand sets for Saturdays, Sundays, and weekdays, plus summer and winter (i.e., six sets).

Weather data are taken from hourly weather service reports for the airport. Parameters used by the model are ceiling, visibility, wind direction, and wind speed. Precipitation data may also be used to identify wet and dry runway conditions.

With the capacity curves, hourly demand, and hourly weather data in hand, we turn to the task of estimating delay. The delay model is run once for each technology case and demand year. The delay model emulates the Traffic Management Unit's decision processes on an hour-by-hour basis. Beginning with the first hour the airport is open, the model examines the ceiling and visibility to determine the airport meteorological operating condition. Next, the model uses the wind speed and direction data to determine which runway configurations are legal. The model then looks to the arrival and departure demand for the hour, including any residual demand remaining from previous hours. The demand data are used to select the operating points on the capacity curves. The arrival and departure capacities of all legal configurations are examined and the highest capacity configuration is selected to determine the airport's capacity for the hour. The model may contain airport-specific restrictions to select preferred configurations or prevent unrealistic flip-flopping among configurations. The demand and capacity data are sent to the queuing routine to determine the delay for the current hour and the residual demand for the next hour. The model then steps to the next hour and continues, hour-by-hour, day-by-day, and year-by-year until the weather data is exhausted. The arrival and departure delays are accumulated and averaged to provide average annual minutes of delay as a function of technology and demand year. From 27 to 35 years of hourly weather data are examined in each model run to produce reliable averages.

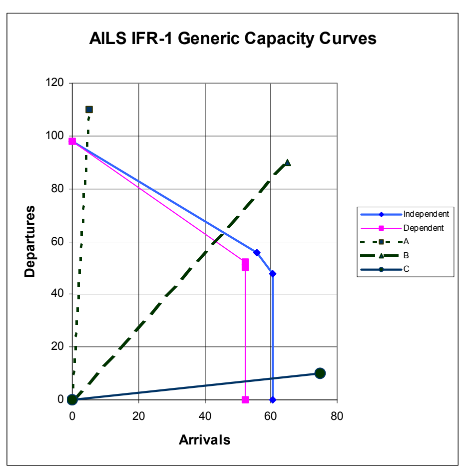
The benefit of the technology is based on the value of the minutes of arrival delay avoided compared to the delay for the baseline. We typically calculate the delays for 2005 and 2015 and interpolate the intervening years using a compound growth factor. The savings for the 10 years, 2006 through 2015 are used to determine 10-year savings for the technology.

Two values of cost per minute of delay are used. The lower of the two includes airlines' variable operating costs (VOC), which do not include capital depreciation, minus fuel and plus flights attendant (FA) costs. The higher of the two includes direct operating costs (DOC), which include both capital depreciation, plus FA costs. The DOC+FA and VOC-fuel+FA define upper and lower bounds on the cost of delay. For this study we use the DOC+FA and VOC-fuel+FA values derived from FAA Form 41 data and reported in the Aviation System Analysis Capability Quick Response System (ASAC/QRS). The values for 1996 in the QRS are $45.74/minute for DOC+FA and $25.11/minute for VOC-fuel+FA in 1996 dollars. We inflate these at a 2.3 percent rate to produce a DOC+FA of $46.79 and a VOC-fuel+FA of $25.69 in 1997 dollars. The average of the DOC+FA and VOC-fuel+FA costs is used for the summary savings table in this chapter while the upper and lower bounds are retained in the savings tables contained in the individual airport chapters. The individual airport chapters also include discounted present value savings for a 1997 base and 7 percent discount factor and inflated (a.k.a. Then Year or Budget) savings for a 2.6 percent inflation rate.

AILS Benefits

AILS enables independent arrival operation of parallel runways with centerline separations between 2,500 and 4,300 feet which, without AILS the runways must operate dependently. Dependent arrival operations require the controllers to maintain 1.5 nautical mile lateral separation between *arriving* aircraft on parallel runways. Since the runways are separated by less than 1.5 nautical miles, arriving aircraft must be staggered to ensure minimum separations, that is two aircraft flying parallel approaches must not be flying side-by-side. Runways with centerline separations less than 2,500 feet must also use dependent *departures* and maintain 1.0 nautical mile lateral separation between aircraft departing parallel runways. Figure 2-2 shows the capacity curves, based on a generic set of input data, for dependent and independent arrivals to parallel runways.[4] In both cases the departures are independent. The radial lines represent typical demand ratios for a departure push, mixed demand, and an arrival push. Independent operation significantly increases arrival capacity during an arrival push (condition C). Capacity gains during mixed operations and departure pushes are smaller.

Figure 1–2. Generic AILS Capacity Curves



[4] the input data are included in Appendix C.

SUMMARY RESULTS

Table 1-2 contains the 10-year constant dollar savings for AILS implementation at the four airports studied.

Table 1-2. Ten-Year Cost Savings (1997 Constant Dollars in Millions) (Based on Average of Variable and Direct Operating Costs per Minute)

Baseline	Total	MSP	DTW	JFK	SEA
Current Technology	554	245	201	18	90
PFAST	470	205	173	17	76
AFAST	267	113	110	12	31

The savings in Table 1-2 for JFK are noticeably low. The results for the other airports are respectable. We spent considerable effort to understand the reasons for the low level of savings at JFK. Two factors emerged from our study.

First, unlike other TAP technologies, AILS applies to a only limited set of runway configurations at an airport, and AILS benefits accrue only when those configurations are used. At JFK low runway configuration usage turned out to be the significant factor limiting AILS benefits.

Second, the switch from dependent to independent operations produces a significant increase in arrival capacity during an arrival push and arrival-heavy mixed operations, but in not during departure push and departure-heavy mixed operations. If an airport experiences a large fraction of departure push or mixed operations during its IFR hours, the benefit from independent operations is reduced.

CONCLUSIONS

Based on the results of our analysis of four airports we conclude the following:

- AILS can produce respectable benefits for airports with runways separated by 2,500 feet
- The benefits from AILS technologies are dependent on airport configuration and operational modes. Benefits are maximized if the AILS-affected parallel runways are the primary runways, and if IFR conditions occur during arrival push demand periods.
- As will be discussed later in the Seattle-Tacoma (SEA) airport chapter, AILS may contribute to the utility of the new SEA runway by providing traffic separation information for aircraft approaching SEA and Boeing Field,

- The benefits in this report accrue from using independent approaches in place of dependent approaches. Larger benefits are expected if two-stream IFR operations, either independent or dependent, can be used with runways separated by less than 2500 feet where only single-stream operations are currently permitted. San Francisco and Boston are two airports where capacity is severely reduced by the requirement for single stream operations in IFR. San Francisco is the more challenging of the two airports because the parallel runways are separated by only 750 feet and because normally staggered dependent operations will not help San Francisco; the need for alternating departure operations from the crossing runways require either side-by-side or closely spaced staggered arrivals to maintain capacity. At Boston the Parallel 4/22 runways are separated by 1,500 feet. Independent arrivals to Runways 4L and 4R with departures from the Runways 4R, 4L, and 9 is a major VFR configuration. In IFR the arrivals are restricted to a single stream to 4R. Independent arrivals to the Parallel 4s in IFR would result in a major increase in capacity. Normally spaced, dependent approaches should also be beneficial, but we cannot know, without analysis, whether dependent approaches would be compatible with the current departure strategy.

- While AILS may enable independent *arrivals* to parallel runways separated by less than 2,500 feet, the FAA also has a 2,500 foot separation minimum on independent *departures*. This limitation will adversely affect capacity when departures are made from the arrival runways or from nearby parallel departure runways.

Recommendations

Based on our analysis and conclusions we make the following recommendations:

- Investigate the use of AILS technology to ensure vertical separation between aircraft on crossing approaches for the Seattle-Tacoma Airport and Boeing Field..

- Continue research on reducing AILS parallel runway separation limits to less than 2,500 feet with the goal of allowing independent (or at least dependent) operations to runways currently reduced to single stream approaches in IFR.

- Analyze the potential benefits of dependent and independent IFR operations at Boston Logan Airport.

- Analyze the ability of AILS to enable independent departures when runway separations are less than 2,500 feet.

Chapter 2
New York Kennedy (JFK)

BACKGROUND AND OPERATIONAL ISSUES

Kennedy Airport has very congested airspace. Approach and departure routes conflict with those of Laguardia and Newark. The congestion results in common path lengths of 12 nautical miles for runways 22L and 22R, and 8 nautical miles for the rest. When using the parallel 31s, runway 31R is used for turboprop departures only. The model will assign some turboprops to the 31L departure mix if needed to balance the turboprop and jet departure rates.

AILS technology at JFK benefits operations on the Parallel 4/22 runways which have a centerline spacing of 3000 feet. Currently, those runways support dependent arrivals in radar controlled approach conditions. AILS allows independent arrivals for Parallel 4 and Parallel 22 configurations.

Figure 2-1 shows the layout of JFK.

Figure 2–1. John F. Kennedy International Airport, New York City

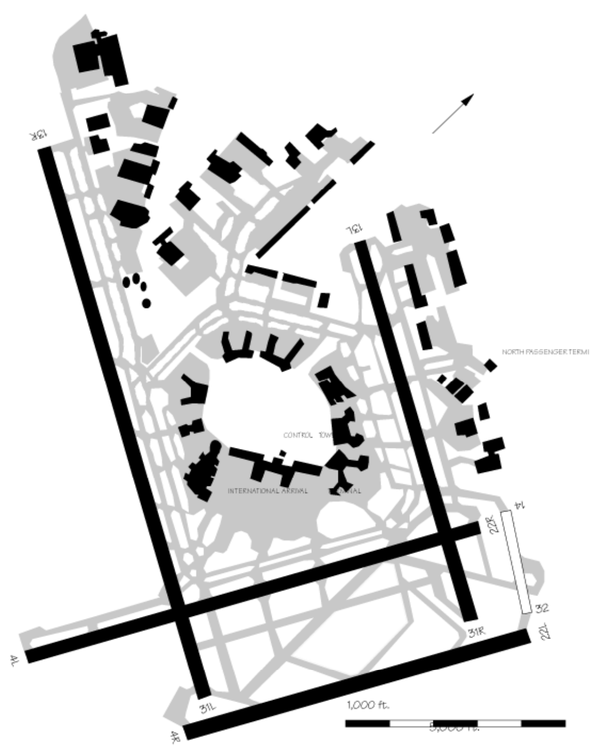


Table 2-1 identifies the JFK runway configurations.

Table 2-1. New York Kennedy Configurations

Configuration	MC	Runway							
		4L	4R	22L	22R	31L	31R	13L	13R
departure only	IFR	D	D	D	D	D	D	D	D
13S OVERFLOW 22	VFR			A				D	A/D
Depart 31L 22R	all			A	D	D			
Arrive 13R 22L	VFR			A	D				A
Arrive 4R 13L	VFR	D	A					A	
Depart 4L 31L	all	D	A			D			
Parallel 31	all						A/D	A/D	
Parallel 4	IFR	A/D dependent							
Parallel 4 AILS	IFR	A/D independent							
Parallel 22	IFR			A/D dependent					
Parallel 22 AILS	IFR			A/D independent					
Parallel 13	all							D	A
Parallel 31 Low Visibility	IFR					D	A/D		
Parallel 4 Low Visibility	IFR	D	A/D						
Parallel 22 Low Visibility	IFR			A/D	A				

A = Arrival only, D = Departure only, A/D = Mixed arrivals and departures

The IFR meteorological condition (MC) in Table 2-1 includes all cases where radar approaches are necessary. Those cases for JFK include all the IFR meteorological conditions plus VFR-2 where the ceiling is < 4000 feet or the visibility is <7 miles. The VFR designation is for true visual approach conditions where the ceiling is ≥ 4000 feet and the visibility is ≥ 7 miles.

Figures 2-2 and 2-3 contain diagrams of the runway configurations.

Figure 2–2. JFK Runway Configurations

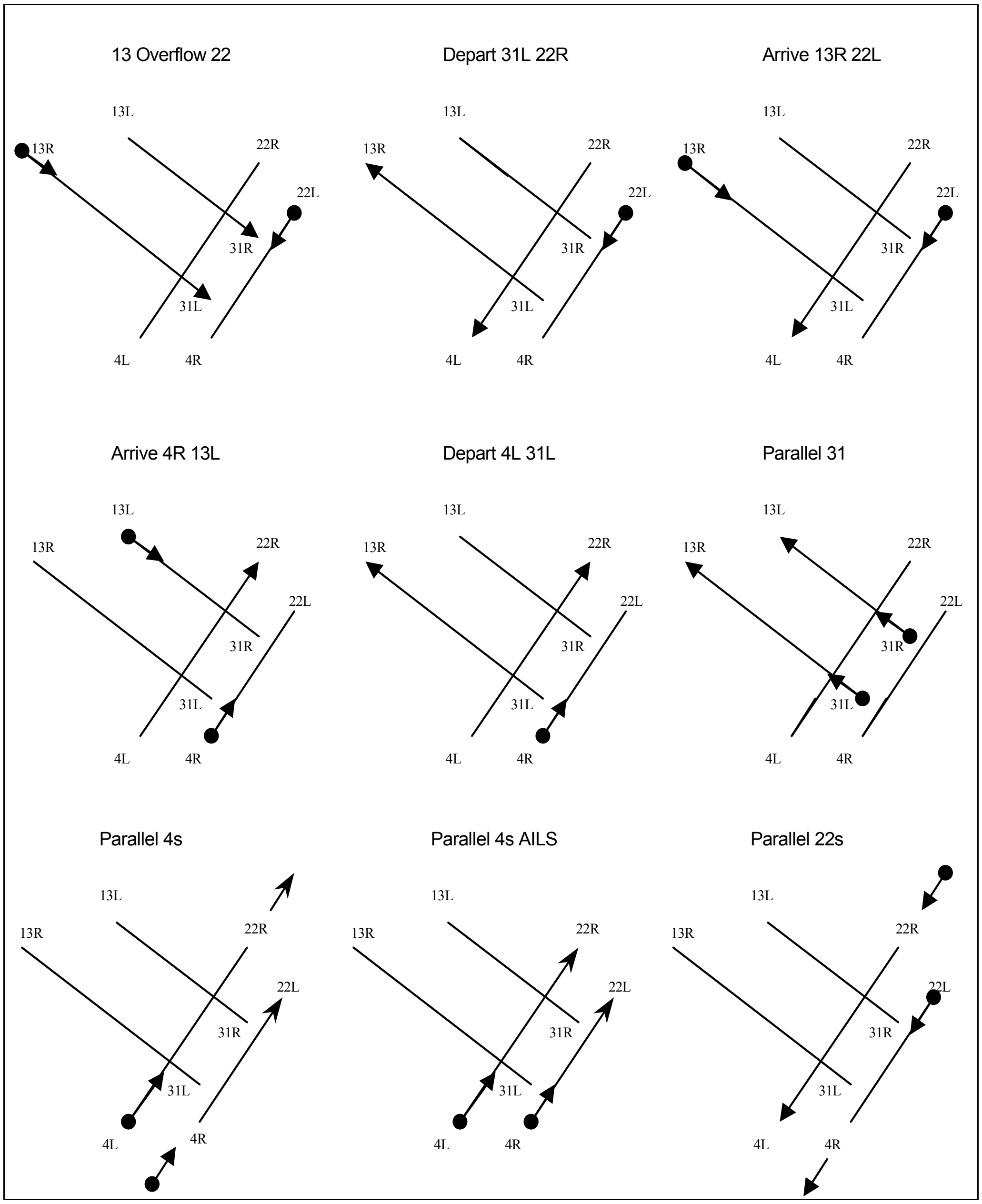


Figure 2-2. JFK Runway Configurations (Continued)

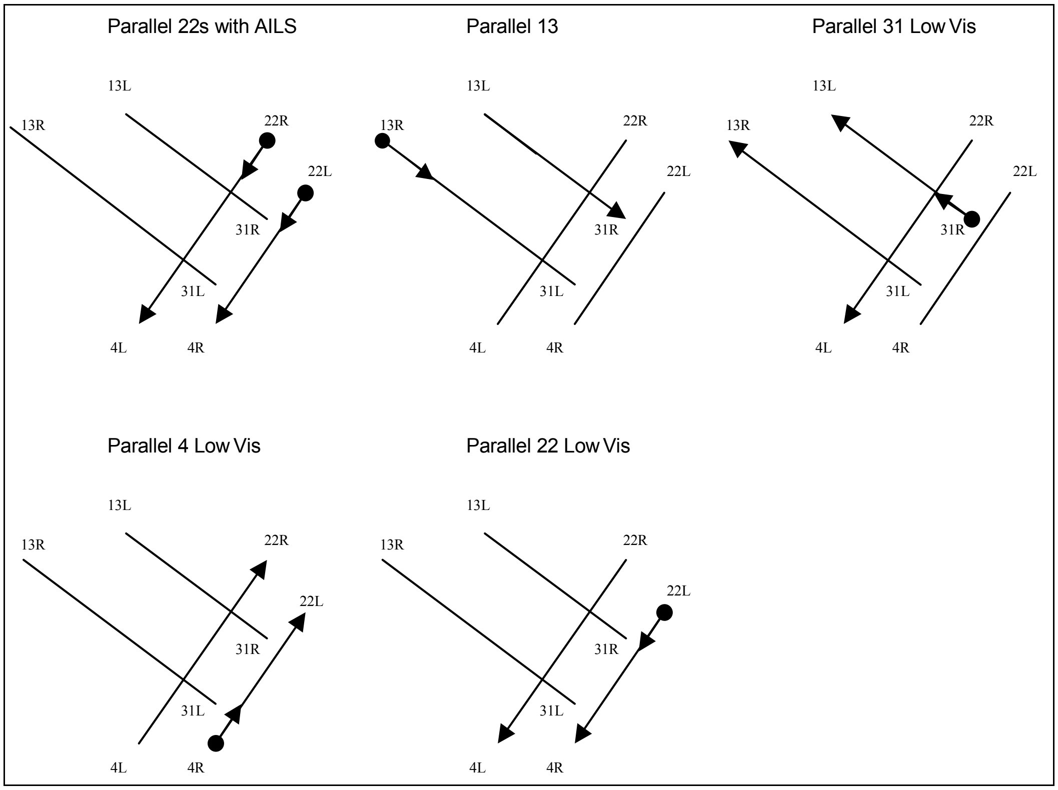
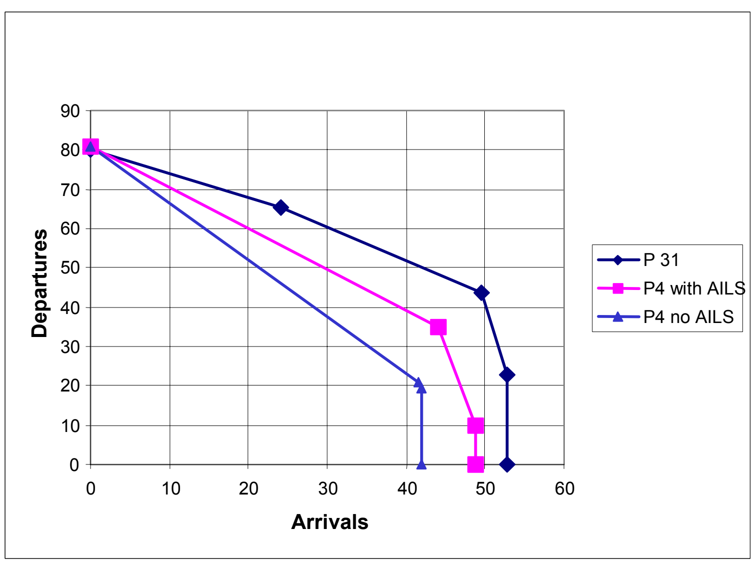


Figure 2-3 shows the capacity curves for the Parallel 4 configuration with and without AILS.

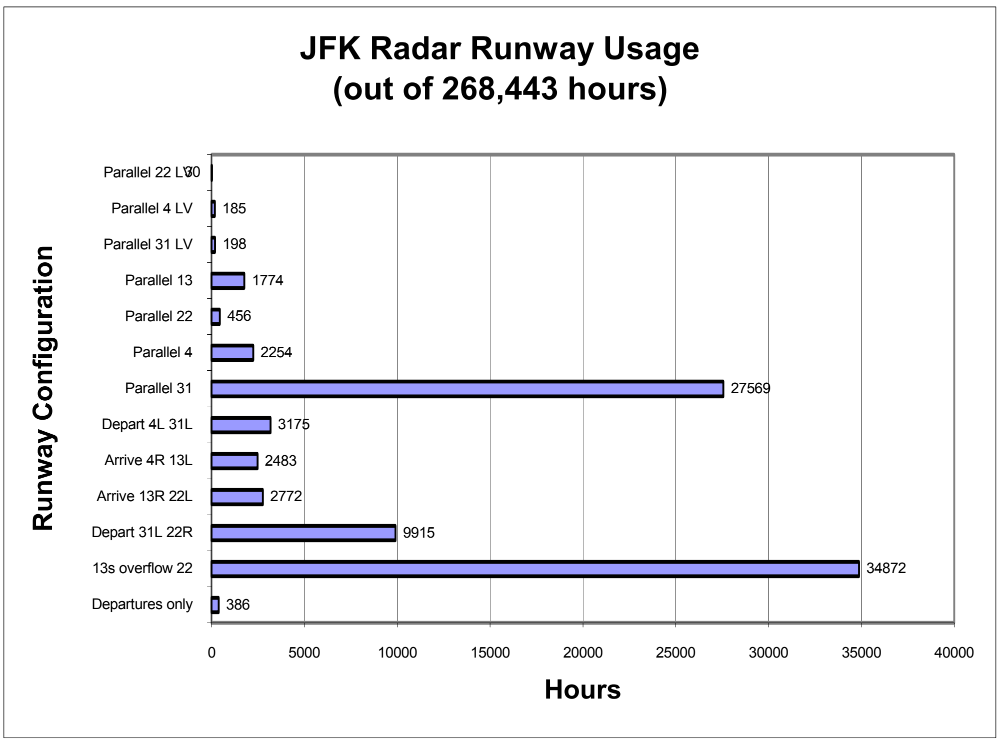
Figure 2–3. JFK IFR-1 Capacity Curves



The curves indicate significant capacity improvement for the Parallel 4 configuration with AILS. Also shown in the figure is the capacity curve for the competing Parallel 31 configuration. The fact that the Parallel 4 configuration with AILS still has lower capacity than the Parallel 31 is a major factor in the small size of the AILS benefit for JFK. Both the controllers and the model choose the Parallel 31 configuration in preference to the Parallel 4 or Parallel 22 configurations whenever possible.

Figure 2-4 shows the runway usage for JFK during radar operating conditions from the model results.

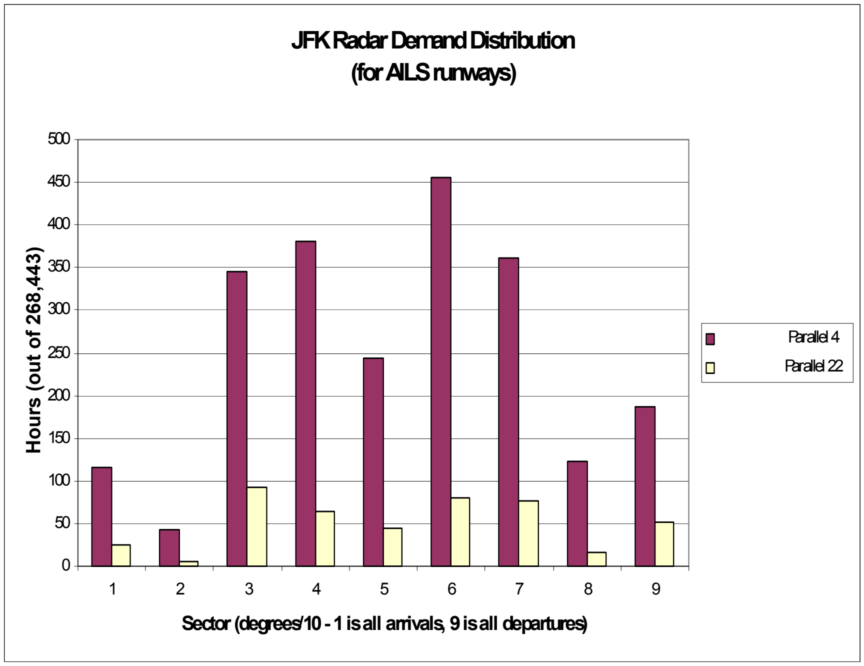
Figure 2–4. JFK Radar Runway Usage



The data in the figure indicate that the Parallel 4 configurations are rarely used. A version of the figure was shown to New York TRACON personnel who said the usage compared well with their experience.

Figure 2-5 shows the demand distribution for the Parallel 4 configuration. For each hour, the program selects from the demand table the arrival and departure demand appropriate for that hour. The residual demand from the previous hour is added to establish the demand for the current hour. The arrival/departure demand ratio determines the location on the runway configuration capacity curve to be used for the hour. Subject to airport-specific constraints, the configuration offering the best capacity at the required demand ratio is selected for the hour. The delay program has been modified in this study to record the demand ratio histories for each runway.

Figure 2–5. Radar Demand Distribution for the Parallel 4 and Parallel 22 Configurations



The angular sector of the demand ratio is determined by calculating the arctangent of departure demand divided by arrival demand and assigning the result to one of 9 sectors. The sectors correspond to 10 degree arcs from 0 degrees (all arrivals) to 90 degrees (all departures). As seen in Figure 2-6, the Parallel 4 and 22 configurations are mostly used in the mixed arrival/departure mode. Neither the all arrival nor the all departure modes are heavily used.

RESULTS

Table 2-2 displays the benefits estimates AILS use at for JFK. The benefits are small.

Table 2-2. JFK Benefits

Scenario	Cost Avoidance compared to:	Minutes millions	1997 Constant $ in millions Lower Bound	1997 Constant $ in millions Upper Bound	Present Value $ in millions Lower Bound	Present Value $ in millions Upper Bound	Then Year $ in millions Lower Bound	Then Year $ in millions Upper Bound
Current Technology with AILS	CT	0.5	$13	$23	$5	$9	$18	$33
PFAST with AILS	PFAST	0.5	$12	$22	$5	$9	$17	$31
AFAST with AILS	AFAST	0.3	$8	$15	$3	$6	$12	$22

Table 3-2 displays the minutes of delay savings for visual and radar approach conditions at JFK. The table shows considerable radar delay per flight in both 2005 and 2015 (the highest of the 4 airports studied). Unfortunately, the impact of

AILS on the delay is small because the AILS supported runway configuration is rarely chosen.

Table 2-3. Current Technology Baseline Results

Demand Year	2005	2015
Arrival Demand (flights)	173,969	191,732
Baseline Delay (minutes)	2,105,791	3,281,874
AILS Delay (minutes)	2,065,172	3,225,001
Savings (minutes)	40,619	56,873
Minutes of Delay per Flight		
Baseline Average	12.1	17.1
Baseline Visual	9.6	13.8
Baseline Radar	34.0	46.0
AILS Average	11.9	16.8
AILS Visual	9.5	13.7
AILS Radar	32.4	43.8
Per Flight Savings (minutes)		
Average	0.2	0.3
Visual	0.1	0.1
Radar	1.6	2.2
Per Flight Savings (percent)		
Average	1.7%	1.8%
Visual	1.0%	0.7%
Radar	4.7%	4.8%

Chapter 3

Detroit Metropolitan Wayne County (DTW)

OPERATIONAL ISSUES AND INFORMATION

Currently at DTW, the primary southwest and northeast configurations have two independent arrival runways and one dedicated departure runway. Construction is underway on a new Runway 4/22, that will be 3,300 feet west of Runway 21R/3L. The new runway was not modeled in previous TAP studies. In radar approach conditions, without AILS, the new runway must be operated in a dependent (staggered) mode with Runway 21R/3L. With AILS, the two runways can always be operated independently.

Figure 3-1 shows the layout of DTW. The new 4/22 runway is located 3,300 feet west of 3L/21R. The current minimum spacing for PRM is 3,400 feet, so the use of PRM to permit independent IFR approaches to 4-3L or 22-21R would require a waiver.

Figure 3–1. Detroit Metropolitan Wayne County Airport, Detroit, Michigan

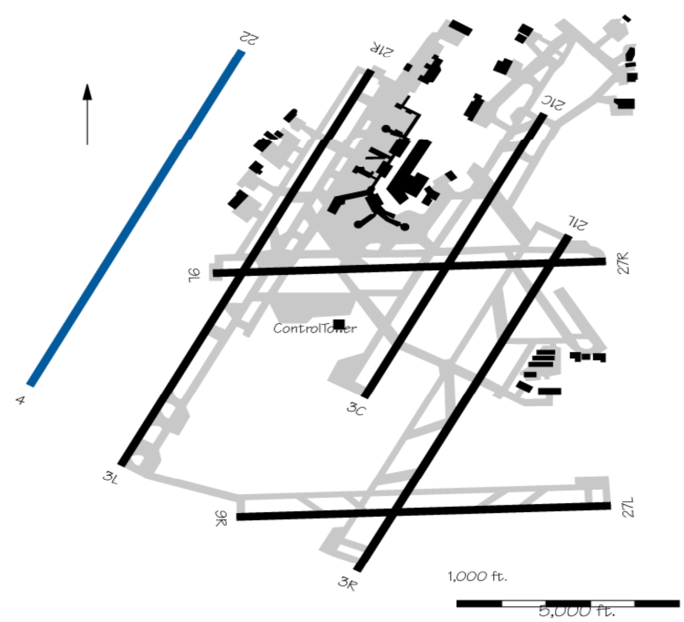


Table 3-1 and Figure 3-2 identify the runway configurations used at DTW. The preferred configuration for DTW is 21L/21C/21R/22 followed by 4/3L/3C/3R. In visual conditions and in radar conditions with AILS these configurations include three independent arrival runways and one dedicated departure runway. Departures can also be handled on the arrival runways at the expense of arrival capacity.

AILS does not impact the Parallel Runway 27L/27R and mixed Runway 27/Runway 21R configurations, but, as will be shown later, those configurations are only rarely used.

Table 3-1. Detroit Wayne County Configurations With New Runway

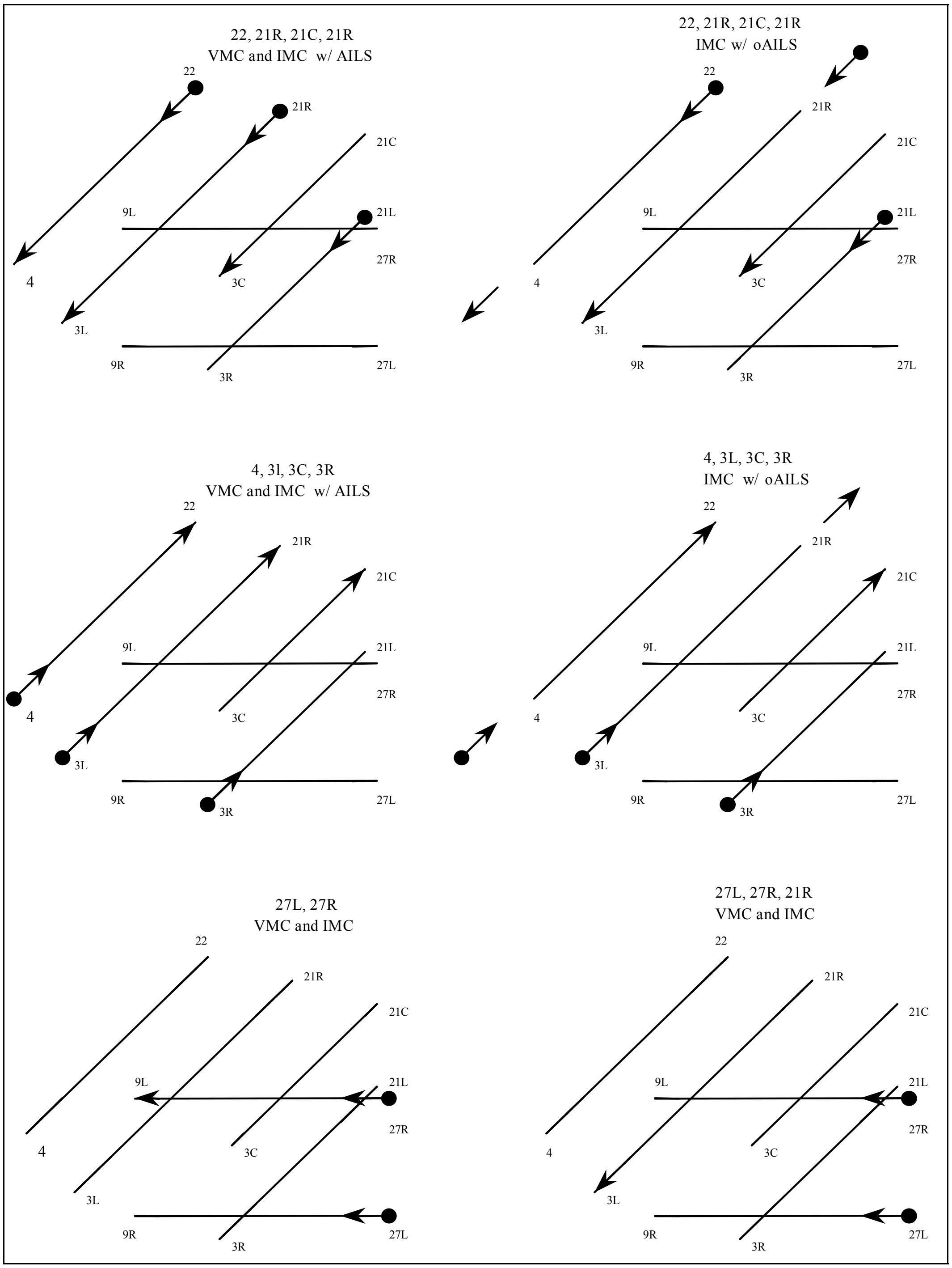
Configuration	MC	Runways											
		22	21R	21C	21L	3R	3C	4	3L	27R	27L	9R	9L
22/21L/21C/21R	IFR w/o AILS	AD dependent		D	A								
22/21L/21C/21R	VFR and IFR with AILS	AD independent		D	A								
4/3L/3C/3R	IFR w/o AILS					A	D	AD dependent					
4/3L/3C/3R	VFR and IFR with AILS					A	D	AD Independ-ent					
27L/27R	All									A	AD		
27L/27R/21R	All		D							A	A		

A = Arrivals only, D = Departures only, A/D = Mixed arrivals and departures

The IFR meteorological condition (MC) in Table 2-1 includes all cases where radar approaches are necessary. Those cases for DTW include all the IFR meteorological conditions plus VFR-2 where the ceiling is < 4500 feet or the visibility is <5 miles. The VFR designation is for true visual approach conditions where the ceiling is ≥ 4500 feet and the visibility is ≥ 5 miles.

Figure 3-2 contains diagrams of the runway configurations.

Figure 3–2. DTW Runway Configurations



At DTW, the runways affected by AILS are the main runways, and the frequency of radar conditions is significant, however, the impact of AILS for current demand levels may be limited by the fact that DTW, with the new runway, will have a high capacity layout with three arrival runways.

The capacity curves shown in Figure 3-3 represent the two closely spaced parallel runways, either Runway 4 and Runway 3L or Runway 21R and Runway 22. As discussed above, the runways operate as part of the two major four-runway configurations. The curves show that AILS provides a significant increase in arrival capacity for the runway pairs.

Figure 3–3. DTW IFR-1 Capacity Curves

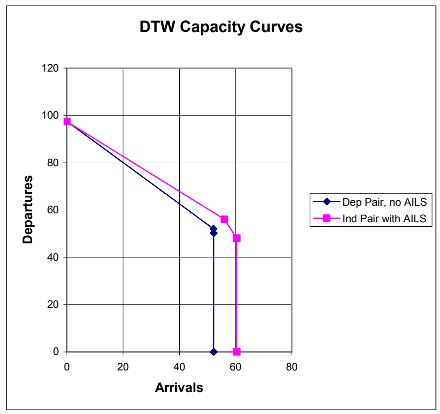
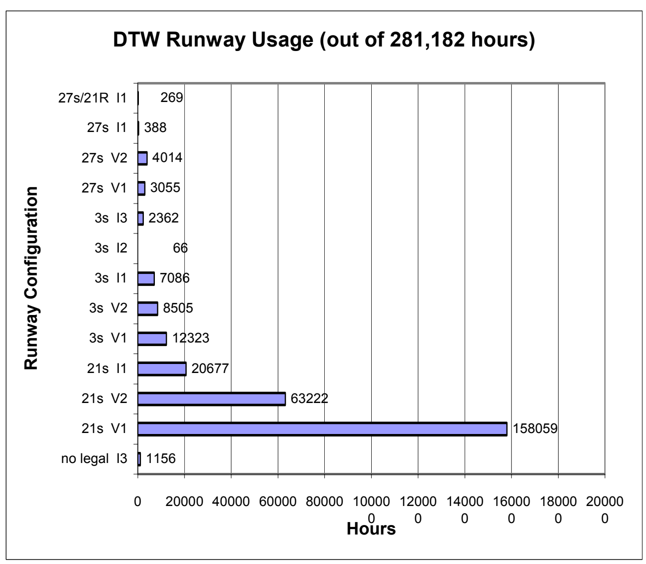


Figure 3-4 shows runway configuration usage at DTW

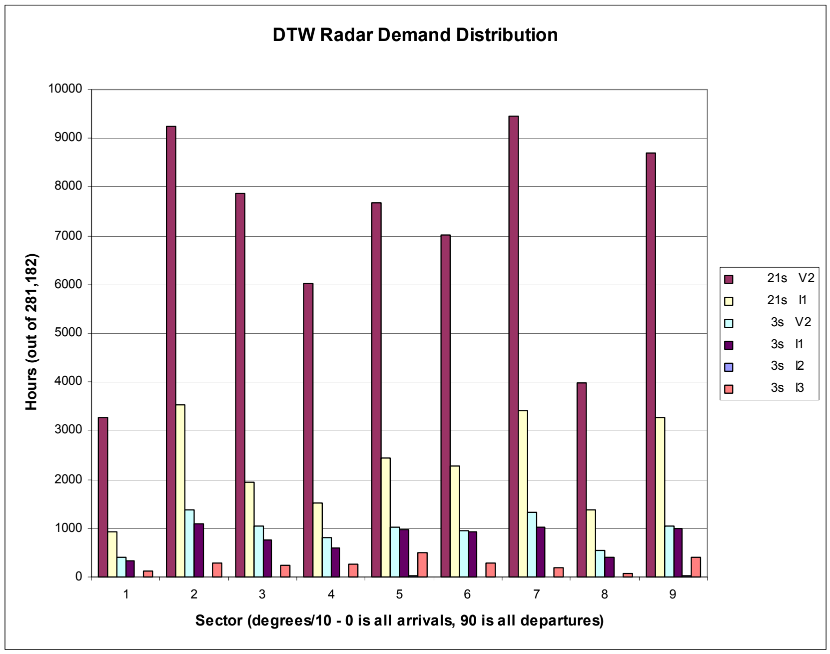
Figure 3–4. DTW Runway Configuration Usage



In the table V1, V2, I1, I2, and I3 stand for VFR-1, VFR-2, IFR-1, IFR-2, and IFR-3 respectively. Radar conditions include V2, I1, I2, and I3. At DTW the dominant configurations are the ones that include the AILS runways. As shown in Figure 3-4, the 21L/21C/21R/22 and 4/3L/3C/3R configurations are used almost exclusively.

Figure 3-5 shows the demand frequency for the dominant configurations.

Figure 3–5. DTW Radar Demand Distribution



Recalling from Chapter 2 that demand sectors correspond to angular positions on the capacity curve with 0 degrees being all arrivals and 90 degrees being all departures, we see that, when the 21L/21/C/21R/22 and 4/3L/3C/3R configurations are used, there is a peak of arrival push conditions, but, for many hours, capacity is determined by the departure-heavy mixed operation and departure push sections of the curve where AILS benefits relative to the baseline are modest.

RESULTS

Table 3-2 displays the estimated benefits for AILS implementation at DTW. The estimated benefits for DTW are significant, ranging from $7.8 million to $25.9 million per year in constant 1997 dollars.

Table 3-2. DTW Benefits

Scenario	Cost Avoidance compared to:	Minutes millions	1997 Constant $ in millions		Present Value $ in millions		Then Year $ in millions	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Current Technology with AILS	CT	5.5	$142	$259	$54	$98	$207	$378
PFAST with AILS	PFAST	4.8	$122	$223	$46	$85	$178	$325
AFAST with AILS	AFAST	3.0	$78	$143	$30	$54	$114	$208

Table 3-3 contains the delay results for the Current Technology cases in 2005 and 2015. We see that the 2015 radar baseline delay at DTW is only 15.2 minutes per flight, indicating that DTW has a lot of basic capacity with the new runway. The AILS savings are still respectable because of the high demand at DTW.

Table 3-3. Current Technology Baseline Results

Demand Year	2005	2015
Arrival Demand (flights)	269,984	346,424
Baseline Delay (minutes)	1,580,936	3,635,883
AILS Delay (minutes)	1,348,186	2,706,755
Savings (minutes)	232,750	929,128
Minutes per Flight Data		
Baseline Average	5.9	10.5
Baseline Visual	5.6	8.1
Baseline Radar	8.6	15.2
AILS Average	5.0	7.8
AILS Visual	4.0	6.3
AILS Radar	6.7	10.4
Per Flight Savings (minutes)		
Average	0.9	2.7
Visual	1.6	1.8
Radar	1.9	5.4
Per Flight Savings (percent)		
Average	15.3%	25.7%
Visual	28.6%	22.2%
Radar	22.1%	34.2%

Chapter 4

Minneapolis-St Paul (MSP)

BACKGROUND AND OPERATIONAL ISSUES

The Parallel 30/12 runways at Minneapolis-St Paul International airport (formerly known as 29/11) are spaced 3380 feet apart. The PRM is installed and operating at MSP. MSP is the site for NASA 1999 AILS testing.

Planning by the FAA for the new 17/35 runway operations is fairly advanced and the anticipated configurations are well defined. One exception is the minima that will be approved for conducting converging approaches to Runway 35 and the Parallel 12's or 30's. We used minima for similar configurations at ORD in the MSP model.

Although the 50-second average arrival ROT is not documented for MSP, (and hence the ability to use 2.5 nautical mile spacing is not currently available), it is anticipated that this certification will be obtained shortly after the new runway opens. The existing exits and traffic mix should easily meet the requirement. It has not been a concern, until now, as current operations space arrivals so as to accommodate an intervening departure, and thus the ability to space arrivals at 2.5 nautical miles would not provide any operational advantage. Where such spacing may provide an advantage, we use it in the analysis.

Figure 4-1 is a diagram of the Minneapolis airport including the runway under construction.

Figure 4–1. Minneapolis-St Paul International Airport

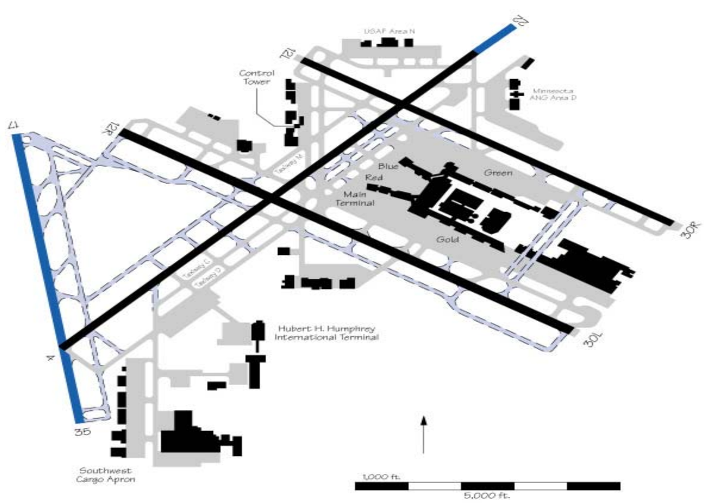


Table 4-1 contains the runway configurations used at MSP.

Table 4-1. Minneapolis-St. Paul Configurations

Configuration	MC	Runway							
		30R	30L	12R	12L	4	22	17	35
departure only	IFR	D	D	D	D	D	D	D	D
30s arrival rush	VFR	A/D	A/D						A
30s departure rush	VFR	A/D	A/D					D	
30s departure rush	IFR	dependent A/D						D	
30s departure rush - AILS	IFR	A/D	A/D					D	
12s arrival rush	VFR			A/D	A/D				A
12 departure rush	VFR			A/D	A/D			D	
12 departure rush	IFR			dependent A/D				D	
12 departure rush - AILS	IFR			A/D	A/D			D	
30s low visibility	IFR	D	A/D						
12s low visibility	IFR			A/D	D				
17-35 west crosswind	VFR	A/D	A/D						
17-35 west crosswind	IFR	dependent A/D							
17-35 west crosswind - AILS	IFR	A/D	A/D						
17-35 east crosswind	VFR			A/D	A/D				
17-35 east crosswind	IFR			dependent A/D					
17-35 east crosswind - AILS	IFR			A/D	A/D				
12-30 sw crosswind	all						A	A/D	
12-30 ne crosswind	all					D			A/D
4 only	all					A/D			
22 only	all						A/D		
17 only	all							A/D	
35 only	all								A/D

A = Arrivals only, D = Departures only, A/D = Mixed arrivals and departures

The IFR meteorological condition (MC) in Table 2-1 includes all cases where radar approaches are necessary. Those cases for MSP include all the IFR meteorological conditions plus VFR-2 where the ceiling is < 3200 feet or the visibility is < 8 miles. The VFR designation is for true visual approach conditions where the ceiling is ≥ 3200 feet and the visibility is ≥ 8 miles.

At MSP the “30s Arrival Rush” and “12s Arrival Rush” configurations allow independent arrivals on three runways (commonly called a triple or “Trip”). The configuration is available in all VFR-1 (visual conditions) and in some VFR-2 conditions. Based on discussions with MSP personnel we set the model to allow Trips in VMC-2 when the ceiling is ≥ 1800 feet and the visibility is ≥ 5 miles. With these limits, Trips are available in 54% of VMC-2 hours.

Figures 4-2 and 4-3 show diagrams of the configurations contained in Table 4-2

Figure 4–2. MSP Runway Configurations

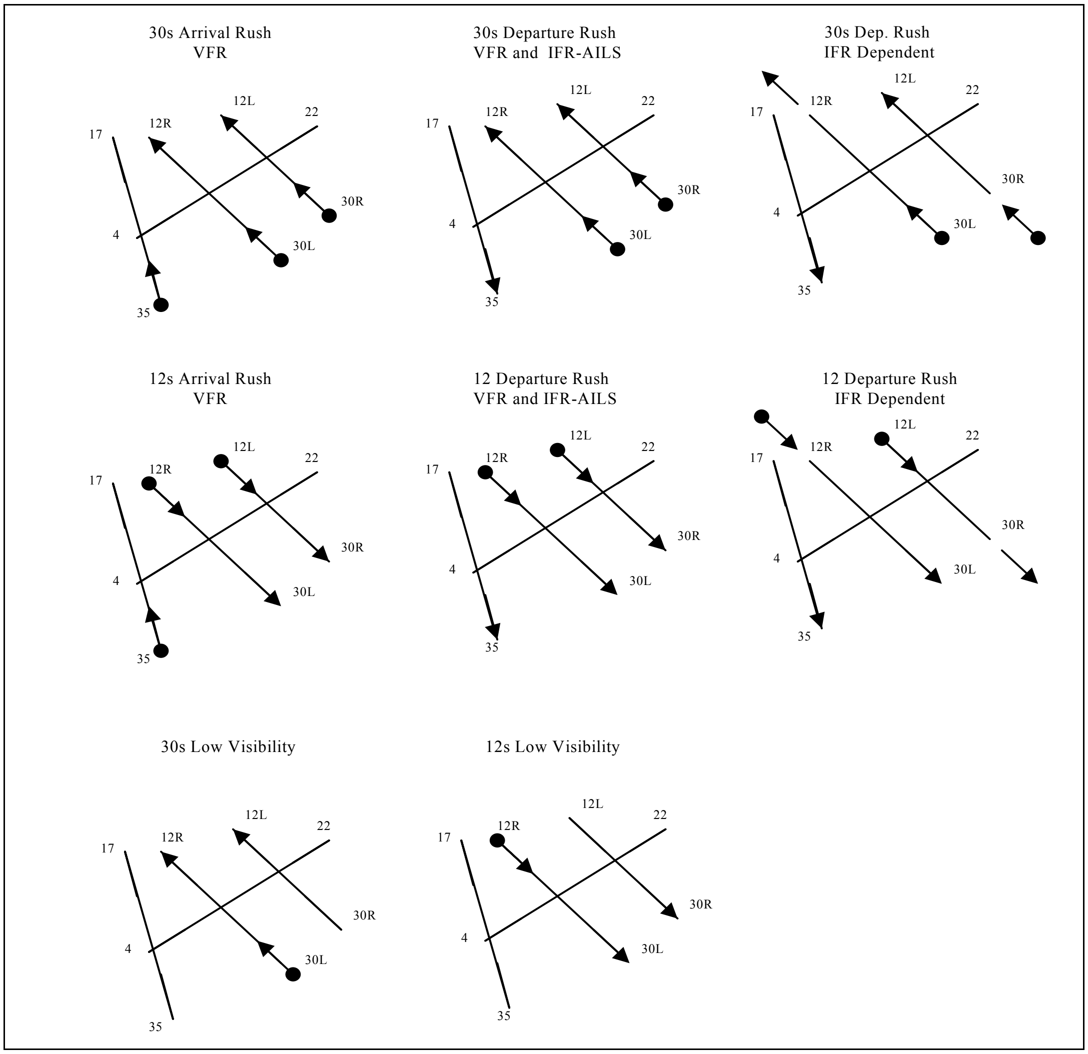
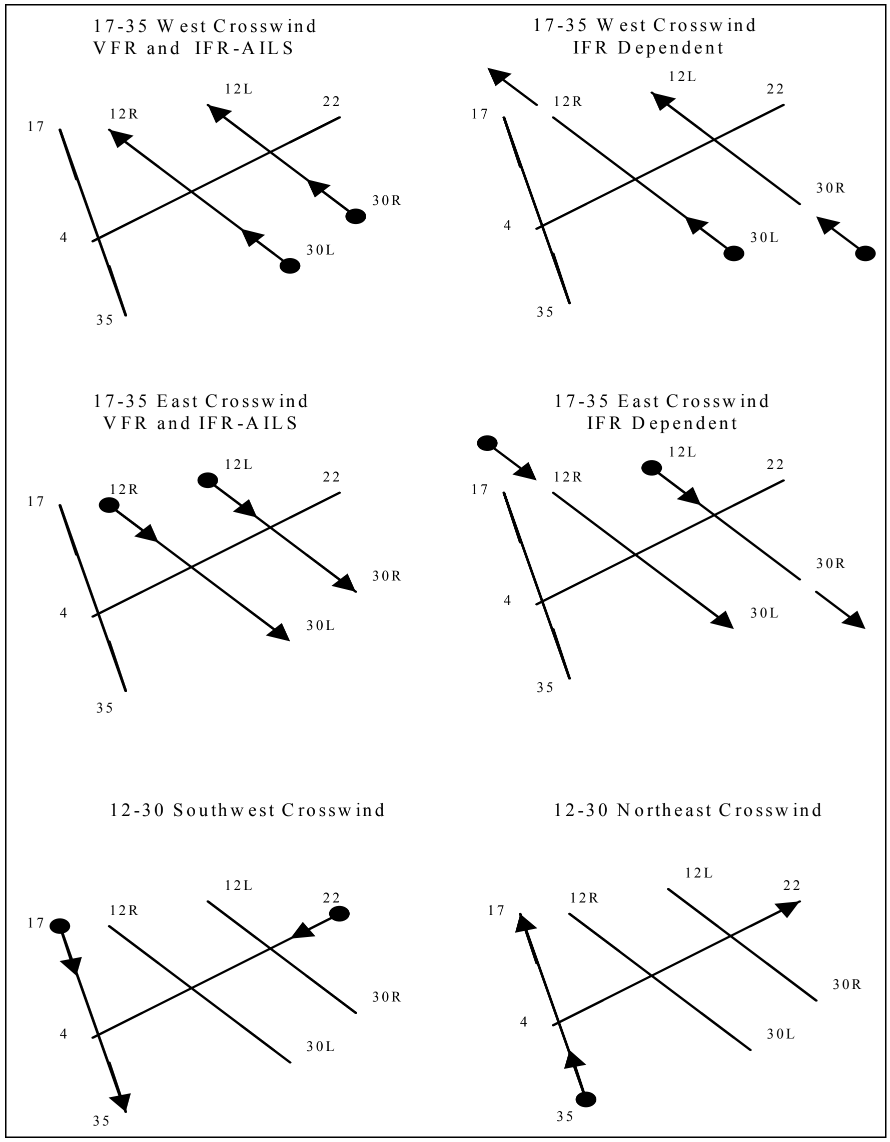


Figure 4–3. MSP Runway Configurations (Continued)



Figures 4-4 and 4-5 show the capacity curves for the Parallel 12s Departure Rush configuration with and without AILS in IFR-1 and IFR-2 conditions. The curves show a substantial arrival capacity increase for AILS in both IFR-1 and IFR-2.

Figure 4–4. MSP IFR-1 Capacity Curves

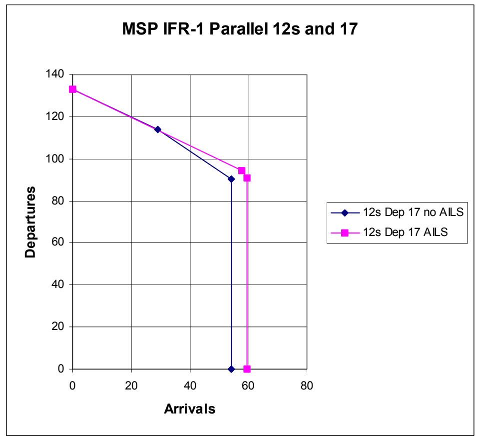


Figure 4–5. MSP IFR-2 Capacity Curves

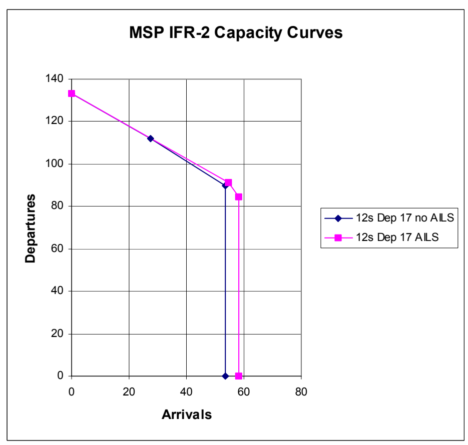


Figure 4-6 shows the runway usage frequency for radar controlled conditions at MSP. IFR and VMC-2 conditions exist 28 percent of the time the airport is open. At MSP, unlike JFK, the AILS impacts the most commonly used configurations.

Figure 4–6. MSP Radar Controlled Runway Usage

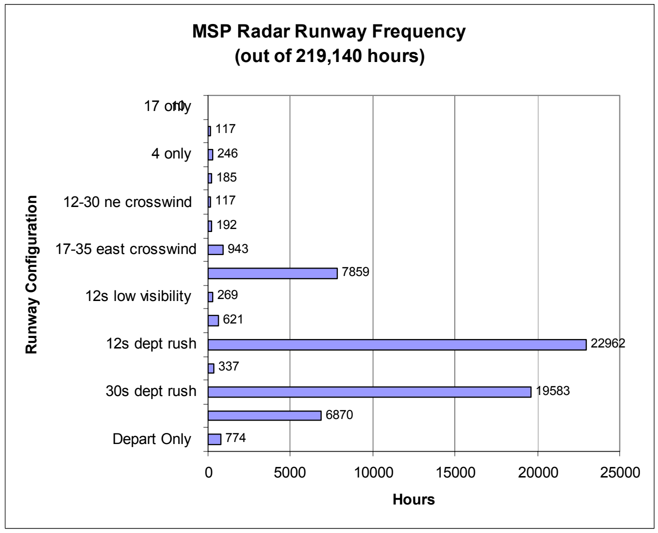
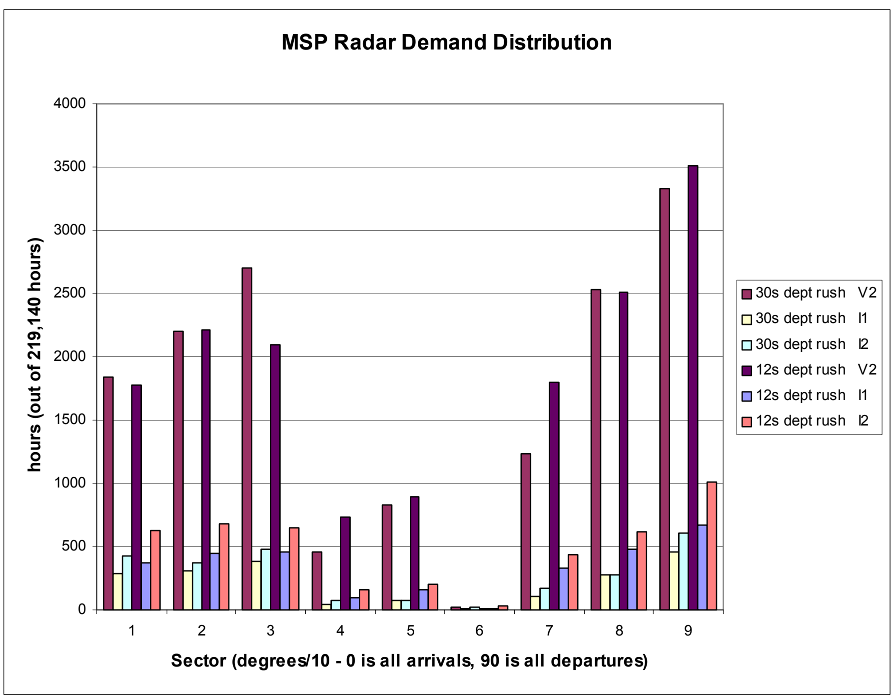


Figure 4-7 shows the demand distribution during radar conditions. MSP shows a definite bimodal demand distribution indicating definite divisions between arrival and departure pushes. AILS provides capacity improvement for the arrival push sectors (i.e. sectors on the left of the chart).

Figure 4–7. MSP Radar Controlled Demand Distribution



RESULTS

Table 4-2 displays the estimated benefits for AILS implementation at MSP. The estimated benefits are respectable, ranging $8.0 million to $31.7 million per year in constant 1997 dollars.

Table 4-2. MSP Results

Scenario	Cost Avoidance compared to:	Minutes millions	1997 Constant $ in millions		Present Value $ in millions		Then Year $ in millions	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Current Technology with AILS	CT	6.8	$174	$317	$66	$121	$253	$461
PFAST with AILS	PFAST	5.6	$145	$264	$55	$101	$211	$284
AFAST with AILS	AFAST	3.1	$80	$146	$31	$56	$117	$212

Table 4-3 contains the Current Technology results for 2005 and 2015. Of the four airports, MSP has the highest projected average IFR delay in 2015. At MSP AILS produces a significant reduction in the delay.

Table 4-3. MSP Current Technology Baseline 2005 and 2015 Results

Demand Year	2005	2015
Arrival Demand (flights)	242,700	299,383
Baseline Delay (minutes)	2,143,671	5,622,374
AILS Delay (minutes)	1,830,576	4,510,127
Savings (minutes)	313,095	1,112,247
Minutes per Flight Data		
Baseline Average	8.8	18.8
Baseline Visual	5.9	12.0
Baseline Radar	17.3	36.2
AILS Average	7.5	15.1
AILS Visual	5.5	11.4
AILS Radar	12.9	24.4
Per Flight Savings (minutes)		
Average	1.3	3.7
Visual	0.4	0.2
Radar	4.4	11.8
Per Flight Savings (percent)		
Average	14.8%	19.7%
Visual	6.8%	5.0%
Radar	25.4%	32.6%

POTENTIAL ADDITIONAL DATA

The PRM radar is already installed at MSP. Since PRM provides the same technical capability as AILS, it would be very useful to collect data on the delay reduction benefits measured for PRM. We note, that because of current FAA rules, measured PRM data will represent only a minimum benefit. Currently, the FAA limits PRM approaches to U.S. carriers; therefore, PRM is only used at MSP when traffic consists almost entirely of U.S. carriers. In practice, this means PRM procedures at MSP are only used during the first morning arrival push.

Chapter 5

Seattle-Tacoma (SEA)

OPERATIONAL ISSUES

Our model of SEA includes some unavoidable uncertainty. Completion of the new runway (16W/34W) is still seven years in the future, and operational procedures are not yet in place. We discussed potential procedures and complicating factors with Seattle FAA personnel. The potential procedures included in our models represent expert opinion on what may work, but are not to be interpreted as a commitment to implement, or even evaluate these procedures. Much more planning, testing, and analysis will be required before formal procedures are developed. Appendix B contains a detailed description of the features of our SEA capacity model.

Visual operations will have a great deal of flexibility with the third runway. Ground operations will become more complicated (and will likely have some capacity impact) as the planned taxiway system requires arrivals to and departures from the new runway to cross both of the current runways.

In radar conditions, arrivals will be staggered to the inboard and outboard runways, with departures between each arriving pair (taxiing traffic permitting). The middle runway is not used, as its departures would require problematic coordination with arrivals and departures on the other two runways. We also explored a strategy with arrivals on the outboards and departures from the center runway only. Such departures need to be coordinated with arrivals to the other two runways to ensure that there is not an arrival within two miles of threshold. It proved to be an inferior strategy.

In radar South flow, interaction with traffic heading to Boeing Field (BFI) located north of SEA becomes an issue. Currently, traffic to SEA is turned onto a course maintaining 1,000 feet vertical separation from BFI traffic, until it has crossed the BFI arrival path. The new runway will require the same separation technique, but BFI traffic will be at a higher altitude (further from the BFI runway). This will make it more difficult for controllers to ensure separation, and there is a possibility that TCAS alerts will begin to wreak havoc with attempts to run approaches to the new SEA 16W and BFI 13 independently.

Today, departures are made on the inboard runway (16L/34R) and arrivals on 16R/34L. In the future, in visual conditions, the new runway (16W/34W) will also be used for arrivals. 16R/34L and 16W/34W are well designed arrival runways with high speed exits. Runway 16L/34R is a well-designed, 11,900 foot departure runway. Because 16R/34L and 16W/34W are only 1,700 feet apart, in radar conditions the arrival runways will switch to 16L/34R and 16W/34W which are 2,500 feet apart. The switching of 16L/34R from departures to arrival and 16R/34L from arrivals to

departures is likely to generate some operational problems. If AILS could support 1,700 foot runway separations the operations would be considerably simplified.

Figure 5–1. Seattle-Tacoma International Airport, Seattle, Washington

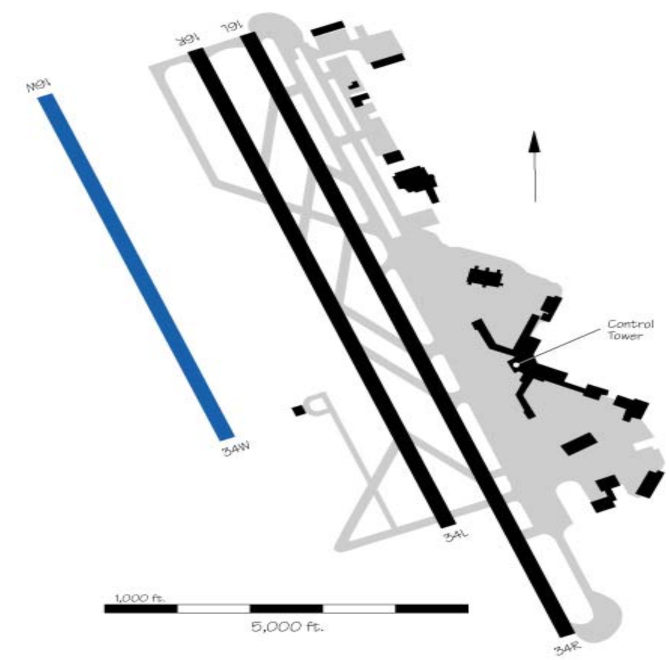


Table 5-1 displays the runway configurations modeled for SEA

Table 5-1. Seattle-Tacoma Configurations

Configuration	MC	Runway					
		16W	16R	16L	34W	34L	34R
Normal South	VFR	A	A or D	D			
Normal South w/o AILS	IFR	A/D Dep.		A/D Dep.			
Normal South with AILS	IFR	A/D Ind.		A/D Ind.			
Normal North	VFR				A	A or D	D
Normal North w/o AILS	IFR				A/D Dep.		A/D Dep.
Normal North with AILS	IFR				A/D Ind.		A/D Ind.

A = Arrivals only, D = Departures only, A/D = Mixed arrivals and departures
Dep. = Dependent arrivals , Ind. = Independent arrivals

The IFR-1 meteorological condition at SEA is defined as the condition in which only single stream approaches are allowed. IFR-1 at SEA has a ceiling limit of 2,500 feet as opposed to 1,000 feet at most airports. Under VFR-2 conditions dual approaches are made today to runways separated by 800 feet using a high altitude instrument approach for one runway and a low altitude visual approach for the other. We assume the same technique will also be used with the new runway configuration with a separation of 2,500 feet. Visual conditions at SEA, therefore, include VFR-2, and radar conditions only include IFR-1 and IFR-2.

Figure 5-2 displays the SEA configurations.

Figure 5–2. SEA Runway Configurations

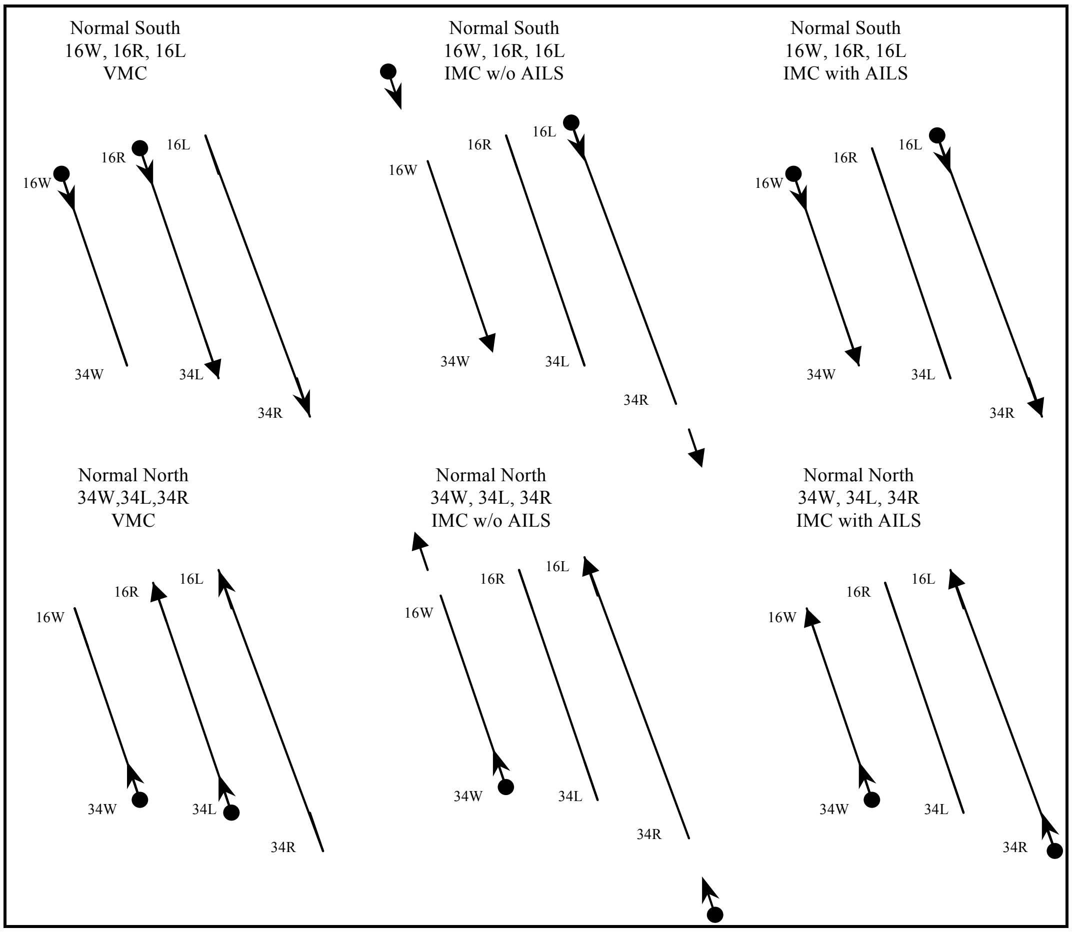
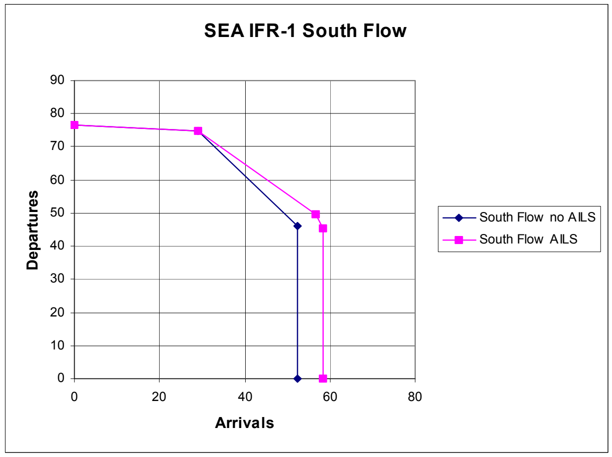


Figure 5-3 shows the capacity curves for the Normal South radar configuration with and without AILS.

Figure 5–3. SEA IFR-1 Capacity Curves



The chart shows that AILS provides a substantial capacity benefit for arrival dominant operations.

Figure 5-4 shows the runway configuration usage at SEA for all meteorological conditions. V1, V2, I1, and I2 equal VFR-1, VFR-2, IFR-1, and IFR-2 respectively. Seattle operates under IFR conditions about 23 percent of the time versus 9 percent–11 percent for the other airports. The higher number for SEA is due to the fact that IFR-1 at SEA starts when ceilings fall below 2,500 feet versus 1,000 feet typical of most other airports.

Figure 5–4. SEA Runway Usage

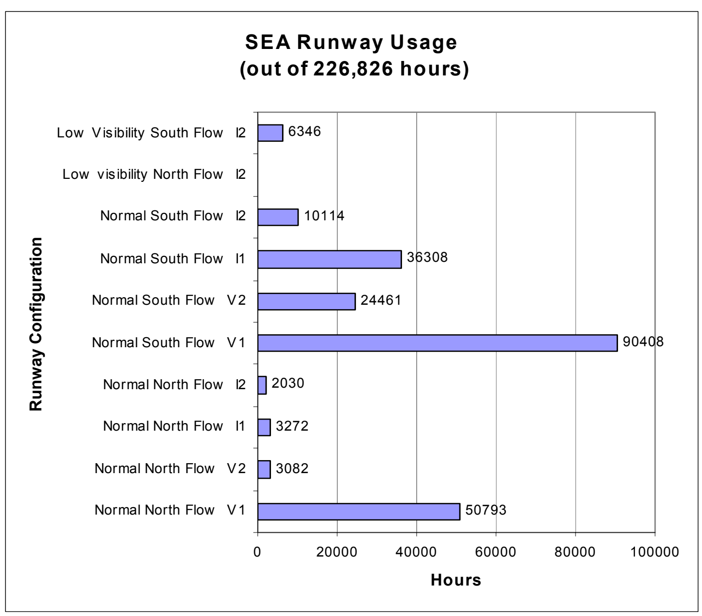


Figure 5-5 shows the IFR (radar) demand distribution for the Normal South Flow and Normal North Flow configurations. The chart shows that few of the hours are operated in the arrival push segments where large AILS benefits occur.

Figure 5–5. SEA Demand Distribution

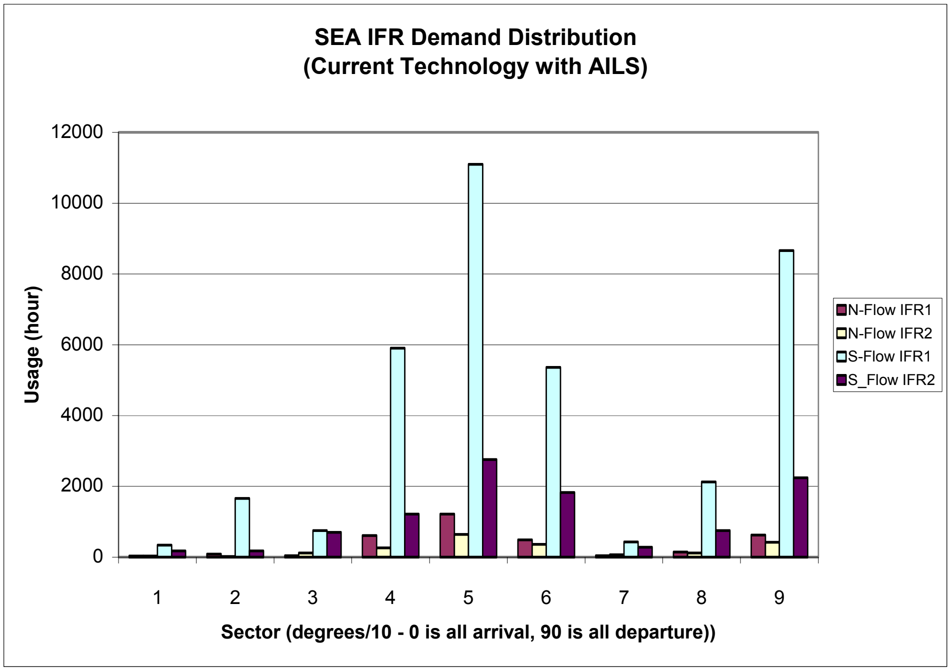
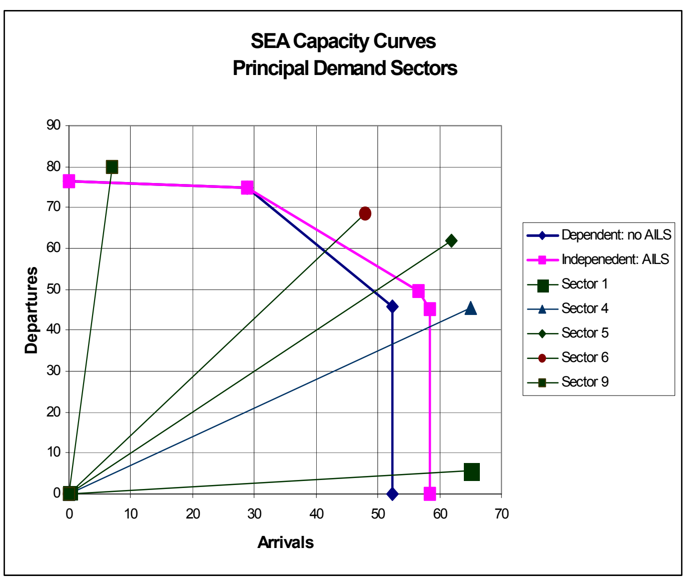


Figure 5-6 shows the SEA capacity curves with the principal sectors marked. The primary benefits at SEA come from those hours with operating points in sector 4.

Figure 5–6. SEA Capacity Curves with Principal Demand Sectors



RESULTS

Table 5-2 contains the benefit estimates for SEA. The estimated benefits for SEA are respectable, but somewhat smaller than we expected. The demand distribution data displayed in Figure 5-5, which we began collecting specifically to investigate SEA, show that that many of the radar controlled hours happen to occur during a departure push or with departure heavy mixed flow.

Table 5-2. SEA Benefit Estimates

Scenario	Cost Avoidance compared to:	Minutes millions	1997 Constant $ in millions		Present Value $ in millions		Then Year $ in millions	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Current Technology with AILS	CT	2.5	$64	$117	$24	$44	$93	$170
PFAST with AILS	PFAST	2.1	$54	$98	$20	$37	$79	$143
AFAST with AILS	AFAST	0.9	$22	$40	$8	$15	$32	$59

Table 5-3 contains the Current Technology results for 2005 and 2015.

Table 5-3. SEA Current Technology Baseline Results for 2005 and 2015

Demand Year	2005	2015
Arrival Demand (flights)	224,948	274,430
Baseline Delay (minutes)	1,412,336	3,156,958
AILS Delay (minutes)	1,314,516	2,729,310
Savings (minutes)	97,820	427,648
Minutes per Flight Data		
Baseline Average	6.3	11.5
Baseline Visual	4.0	5.9
Baseline Radar	13.4	29.3
AILS Average	5.8	9.9
AILS Visual	4.0	5.5
AILS Radar	11.8	23.9
Per Flight Savings (minutes)		
Average	0.50	1.60
Visual	0.00	0.40
Radar	1.60	5.40
Per Flight Savings (percent)		
Average	7.9%	13.9%
Visual	0.0%	6.8%
Radar	11.9%	18.4%

As mentioned previously, the new radar controlled configurations for SEA, both with and without AILS, require shifting the normal departure runway 16L/34R to an arrival runway. To avoid this shift, and hopefully to improve capacity, we analyzed the case where AILS would allow independent operations with runway separations of 1,700 feet and enable the radar and visual configurations to use the same arrival runways. Unfortunately, the restrictions on independent *departures* when separations are below 2,500 feet resulted in the 1,700 foot AILS case having lower capacity than the 2,500 foot AILS case. The 1,700 foot capability may still be attractive to simplify operations both in the air and on the ground. The capacity would approach that of visual operations if AILS could support independent departures with 1,700 foot runway separations.

AILS will also benefit SEA if it can enable pilots to ensure vertical separation between SEA-bound and BFI-bound aircraft. As mentioned above, aircraft using the new SEA runway must maintain a 1,000-foot vertical separation from aircraft using Boeing Field. Lack of a precision vertical separation capability may hamper the use of the new runway in radar conditions.

References

[1] *Benefit Estimates of Terminal Area Productivity Program Technologies*, NASA/CR-1999-208989, Hemm, Shapiro, Lee, Gribko, and Glaser, Logistics Management Institute, McLean, VA, Jan 1999.

[2] *Proceedings of the NASA Workshop on Flight Deck Centered Parallel Runway Approaches in Instrument Meteorological Conditions*, NASA Conference Publication 10191, Waller and Scanlon, ed., Langley Research Center, Hampton, VA, Dec 1996.

Appendix A
Seattle Model

General Notes:

There is not yet an operational plan for air traffic with the new runway at SEA. The model described in this appendix uses assumptions based on discussions with air traffic professionals familiar with current SEA operations. Any statements about future operational procedures are not to be interpreted as policy approved by the FAA or its employees.

Departures

In South flow, the jet departure path length is 5 miles. In North flow, eastbound jets (40 percent of departures) travel 8 miles; westbound traffic travels 5 miles. For simplicity we use a departure path of 6.5 miles for all jets in North flow.

Two Departure Runways

With the addition of a third runway, many operational scenarios will be available in which two departure runways can be used. At SEA propeller driven aircraft can be fanned out on departure, whereas jets must follow a corridor for noise-impact abatement. In our model almost all jets depart from the same runway. This will facilitate departure spacing along the noise-impact corridor.

We assign prop departures in each operating mode so that proportion of prop departures in each mode is equal to the long-run proportion of departures that are propeller driven aircraft. (The hourly fluctuations in traffic mix are not represented in the model.) In some operating modes, props will be mixed in with the jet departures. In other operating modes, the departure rate on the prop-only departure runway will be limited to achieve the required balance.

When propeller driven aircraft are mixed in with the jet departures, we assume that they can be turned within one mile of the runway end, and need not fly the entire noise-abatement route. This implies that props may be fanning out from two runways, although not very often from the one that primarily handles jets.

The model assumes that all small aircraft and 29 percent of large aircraft are turboprops.

ARRIVALS

We assume that IMC capacity is not limited by interaction with Boeing field (BFI) traffic.[1] This may be an optimistic assumption, but allows evaluation of the maximum benefit that AILS can provide. In fact, AILS technology may itself enable procedures to permit independent operations of SEA and BFI traffic.

The existing Bay Visual approach to 16R has minima of 3,100-foot ceiling and 4 statute mile visibility (3,100 and 4). We assume that VMC-1 (visual approaches) will continue to hold in South flow, including to the new runway, above 3,100 and 4. The existing Mall Visual to the 34's has minima of 3,100 and 7, during daylight hours. We assume that VMC-1 will continue to hold in North flow, including to the new runway, above 3,100 and 7, during daylight hours. Daylight hours are assumed to be 6 A.M. to 9 P.M. in "summer" (June through September) and 7 A.M. to 7 P.M. otherwise. VMC-1 conditions are assumed to exist above 5,000 and 5 in North flow during darkness.

Runway 34R goes below ILS minima at 200 and 3/8; runway 16L goes below ILS minima at 200 and ¾. We assume that the minima to the new runway are no better, so these conditions will permit only one runway to be used for arrivals, in North and South flows, respectively.

MIXED OPERATIONS IN IFR-2

Below 800-foot ceiling and 2 mile visibility, capacity is reduced on 16L and 34R when these runways used for mixed arrivals and departures. Departures must wait until the arrival has the runway end in sight before taxiing into position, in order to protect the ILS. Due to the location of the ILS hold lines, the time between releasing a departure from the ILS hold line until it is ready to depart is considerable on the eastern runway. We use 45 seconds after the arrival has exited before a 16L departure is ready to roll, and 48 seconds on 34R. For the new runway, we use only a 6-second delay after the arrival has exited before departures roll, consistent with other airports we have modeled.

VMC CAPACITY MODEL

In VMC, the eastern runway will be used for departures, the new (western) runway for mixed operations or arrivals only, and the center runway (current western runway) for hourly dominant demand.

When the center runway is used for arrivals, the model adds spacing to the center runway IAT's, to permit arrivals from the outer runway to taxi across. (Operationally, arrivals are metered so as to accommodate the arrival rate corresponding

[1] Intrument meteorological conditions (IMC) and visual meteorological conditions (VMC) are identical to Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) respectively.

to maximum arrivals on the new runway and arrivals with extra inter-arrival spacing to the center runway.) There were two alternatives to adding extra time between all arrivals to the center runway considered, but rejected: 1) Insert time between every fourth pair, and not between others and 2) Operate the center runway with both arrivals and departures, holding departures to allow for crossings. The first option would make TRACON operations more complex and introduce additional chances for safety problems. The second option would make ground operations more complex; departures from the center runway would need to be coordinated both with arrivals to the center runway and with departures from the eastern runway.

Currently, the extra gap inserted to the center runway inter-arrival times is about 40 seconds, (30 seconds nominal for crossing plus safety margin). It is assumed that two aircraft can taxi across the runway in this time. The user can modify the nominal time in the capacity model input file.

In the VMC two-arrival-runway mode, we assume that the bulk of the turboprop traffic departs from the new runway, as gaps in the arrival stream permit. (Typically, 20-25 such departures can be achieved in an hour.) The departures taxi across the eastern two runways in the same gaps used to taxi outer runway arrivals across.

We assume that all VMC jet departures are from the eastern runway. If the new runway turboprop departure rate is below the fraction of turboprops in the SEA traffic mix, we assign a percentage of turboprop departures to the eastern runway. This percentage is calculated to bring the turboprop departure rate relative to jet departure rate into balance with the ratio of these aircraft types in the traffic mix. The eastern runway departure rate is simultaneously adjusted to account for the turboprops in the runway mix; mathematical techniques are used to find the fraction of turboprop departures that will utilize the eastern runway. (Although for tactical reasons, and due to varying traffic mixes, the ratio of turboprop to jet departures will vary considerably by hour during a typical day, departures rates based on these imbalances would not reflect the long-run capacity of the airfield.)

Departures from the new runway and eastern runways are independent. Turboprop departures (from either runway) are assumed to be turned to avoid separation conflicts with jets on the noise abatement track.

The second operating mode modeled in VMC uses the center and eastern runways for departures. Here we assume that all jet traffic departs from the eastern runway, and that turboprops use the center runway and are fanned out. We assume that there is one turboprop departure after each non-heavy jet departure. Although it may be possible to release two turboprops after jet departures which require eight miles before turn, the proportion of turboprops in the SEA mix is less than half, so the reduction in theoretical departure capacity resulting from the 1:1 assumption should not impact actual departure capacity. In fact, we limit the turboprop departure rate so that turboprop departures do not account for more than their long-term percentage of total departures.

In both operating modes modeled, departure rates are adjusted to account for the intervals when operations must be suspended on a runway to allow arrivals to taxi across. The algorithm accounts for the number of crossings that are "free", as traffic must be held after heavy jet departures, in any case, and some inter-departure times between large jets may be large enough to permit crossing aircraft, with zero or very little departure delay. Departure runway crossing time is the same as is used for crossing an arrival runway, but no safety margin is added.

The SEA delay model assigns hourly capacity by interpolation between the arrival heavy and departure heavy modes, capturing the ability to rapidly change from one mode to the other. There are certainly other operating modes conceivable in VMC, but the two described here combined with interpolation should model the range of arrival/departure rates that can be achieved.

IMC Capacity Model

The model evaluates capacity for a number of IMC runway strategies. Some strategies may prove to be inferior, either by being dominated by another strategy (one that simultaneously provides greater arrival and departure capacity) or by providing fewer total operations per hour than trading off between two other strategies during the hour. The model identifies and removes inferior strategies from the capacity trade-off curve.

Runway dependencies in IMC limit the available strategies. For instance, the VMC strategy of departing from both existing runways and arriving to the new runway is not modeled as an IMC strategy. In addition to coordinating the center runway departures with the eastern runway departures, the center runway departures would need to be coordinated with arrivals. This would be a difficult operational strategy to manage.

IMC Capacity—One arrival stream

We model an all departure mode, with jets departing one runway, turboprops the other, and turboprop departure rate limited to its fraction of total operations. We also model arrivals to the new runway with turboprop departures in the IAT gaps (one mode has arrivals metered to allow 1:1 arrival to departure rate, another maximizes arrivals and releases departures as possible), along with jet departures from the eastern runway, adjusted for the need to taxi across. Turboprop departures are added to the eastern runway mix, or limited, as needed to bring the departure rates of the two engine types into the correct ratio.

Another single arrival stream mode uses the center runway for arrivals (with spacing allowing for crossing traffic) and departures from the eastern and new runways. These departures are independent of one another, but are both dependent on the arrivals. In principle, one could achieve a 2:1 departure to arrival rate, but since turboprops are less than 50 percent of the mix, the actual ratio is less. We assume that the inter-departure gaps created by coordination with center runway arrivals are adequate to taxi arrivals and new runway departures across the eastern runway.

IMC Capacity—Two arrival streams

Arrivals must use the new runway and the eastern runway. If the center runway is used for arrivals, it is too close to the other two to permit staggered or AILS operations. Departures can be accommodated on the same runways as used for arrivals, either by spacing to permit 1:1 or releasing departures as IAT gaps permit. In staggered operations, 1:1 must be used on both runways or on neither. In AILS operations, we can choose runway strategies independently for each runway. The maximum eastern arrival rate (independent arrivals) and the maximum staggered rate both incorporate additional spacing to allow for traffic to taxi across the runway. In 1:1 operations, departures are adjusted to account for crossing traffic.

When using both arrival runways also for departures, it will be the new runway that has higher departure capacity, as eastern runway departures must be held for taxiing traffic. Since jets are the bulk of the SEA traffic, we assume that they will use the new, higher departure capacity runway. Since heavies may request or require the longer eastern runway, we assume that the traffic mix on this runway consists of heavies and turboprops. As with the VMC operating modes with two departure runways, turboprop departure rate may be limited, or some fraction of turboprops and heavies may be assigned to the outer runway, as needed to bring departure rates by aircraft type into balance with their proportion of the airport mix.

As arrival runway occupancy times (ROT's) on the eastern runway are longer than on the new runway, it is the former's capacity that will dictate tempo under staggered operations. We adjust departure rates to account for traffic taxiing across the eastern runway, and to assure that turboprop departures do not exceed their proportion of the mix.

For staggered approaches, we also model the strategy of departures from the center runway only. These departures are released when arrivals to the eastern runway cross the threshold. Since the stagger is set up to allow for crossing time on the eastern runway, the departing aircraft should be able to roll and cross the runway end (or suitable visual reference) before the arrival to the new runway crosses the threshold. It is unlikely that the time between an arrival to the eastern runway and an arrival to the new runway is adequate to permit two departures (the first departure will not have progressed very far). The model assumes one departure for every pair of arrivals (i.e. 1:1 with the eastern runway, with stagger spacing ensuring that dependencies with the outer runway are met). We assume that no departures are lost due to arrivals taxiing across the departure runway.

Appendix B
Weather Data

When the benefits for New York Kennedy (JFK) turned out to be small, we thought to look at the combined IFR and VFR-2 conditions in more detail than we had previously. Toward that end, we developed a program to examine the weather data and analyze the frequency of combined IFR and VFR-2 conditions as a function of months and hours. We also, examined the frequency that combined IFR and VFR-2 conditions existed continuously for 2, 3, and 4 hours.

The weather analysis did not fully explain the low benefits, but the results are of general interest, and we, therefore, include them here for all four airports. The definitions of IFR and VFR-2 conditions used are specific to each airport. Tables B-1 through B-4 contain for each airport the ceilings and visibilities that determine the meteorological operating conditions.

Figures B-1 through B-4 display the fraction of the time that radar controlled approaches are used at each of the four airports. At JFK, DTW, and MSP radar approaches are used during IFR-1, IFR-2 and VFR-2 meteorological conditions. At SEA, dual independent approaches are allowed during VMC-2 and "radar" operations apply only during IFR-1 and IFR-2 operations. Note that the IMC-1 limits in Table B-4 for SEA are higher than those for the other airports.

The figures are based on the average of all the weather year data available: 35 years for JFK and DTW, 30 years for MSP, and 27 years for SEA.

Table B-1. New York Kennedy Meteorological Operating Conditions

Meteorological condition	Ceiling (feet)	Visibility (statute miles)
VFR-1	$c \geq 4000$	$v > 7$
VFR-2	$1000 \leq c < 4000$	$3 \leq v < 7$
IFR-1	$700 \leq c < 1000$	$2 \leq v < 3$
IFR-2	$c < 700$	$v < 2$

Figure B–1. New York Kennedy Radar Approach Frequency

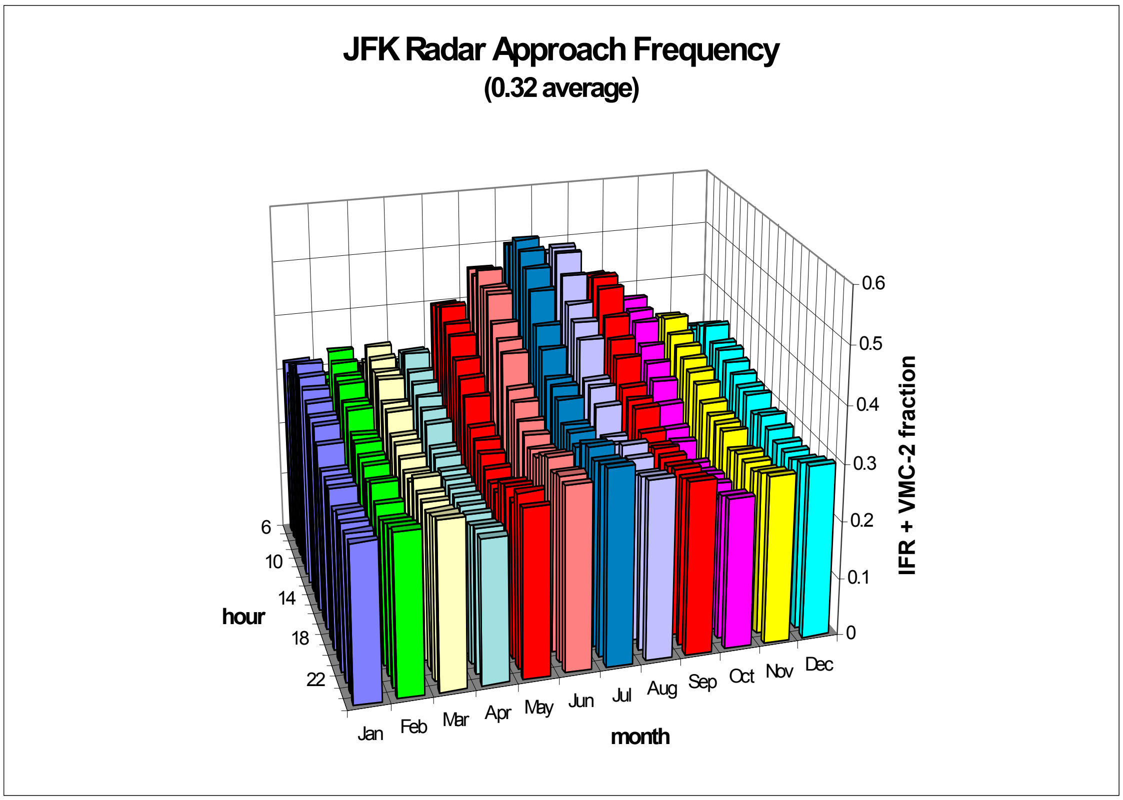


Table B-2. Detroit Meteorological Operating Conditions

Meteorological condition	Ceiling (feet)	Visibility (statute miles)
VFR-1	$c \geq 4500$	$v > 5$
VFR-2	$1000 \leq c < 4500$	$3 \leq v < 5$
IFR-1	$200 \leq c < 1000$	$0.34 \leq v < 3$
IFR-2	$200 \leq c < 1000$	$0.3 \leq v < 0.34$
IFR-3	$c < 200$	$v < 0.3$

Figure B–2. Detroit Radar Approach Frequency

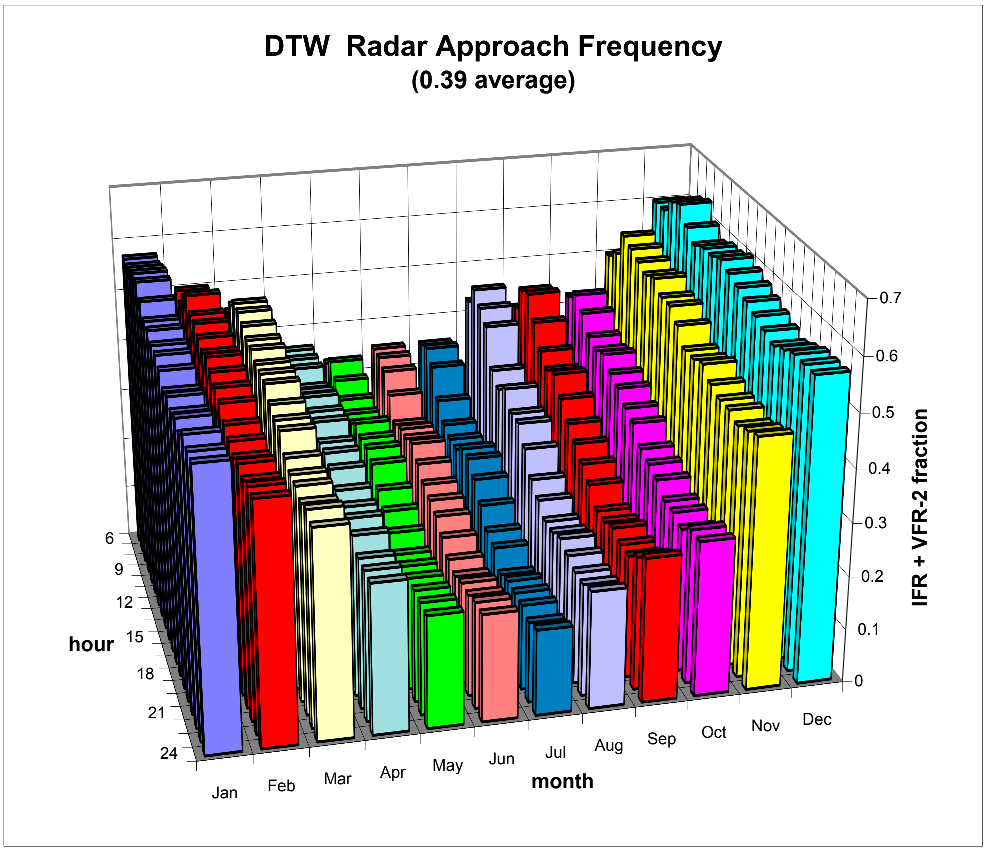


Table B-3. Minneapolis-St. Paul Meteorological Operating Conditions

Meteorological condition	Ceiling (feet)	Visibility (statute miles)
VFR-1	$c \geq 3200$	$v > 8$
VFR-2	$1000 \leq c < 3200$	$3 \leq v < 8$
IFR-1	$700 \leq c < 1000$	$2.0 \leq v < 3$
IFR-2	$c < 700$	$v < 2.0$

Figure B–3. Minneapolis-St. Paul Radar Approach Frequency

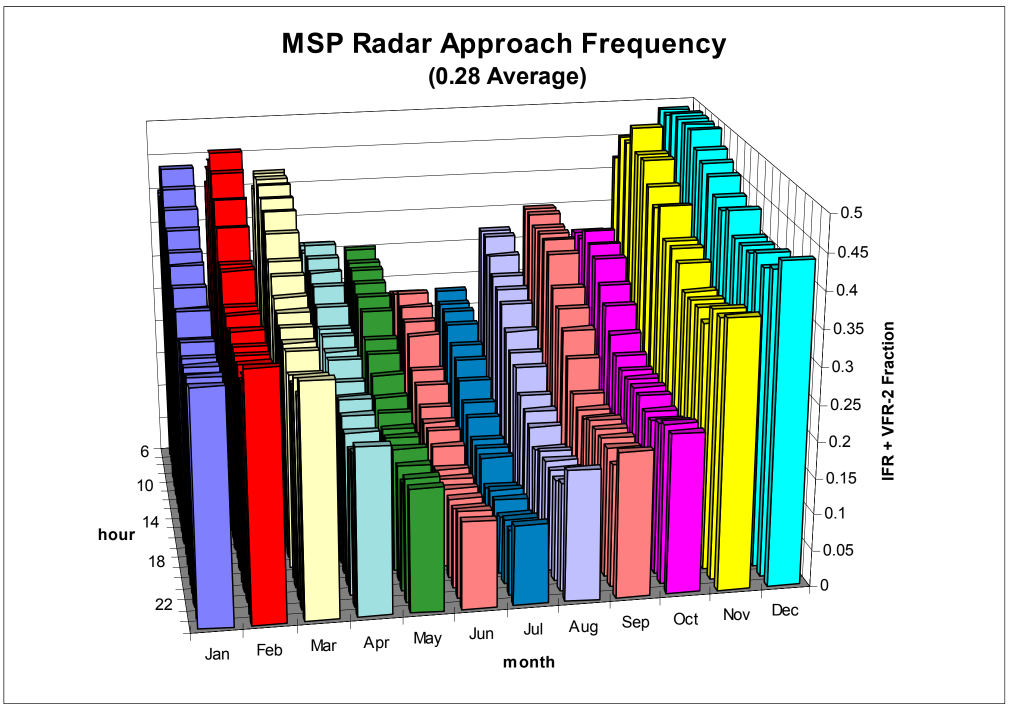
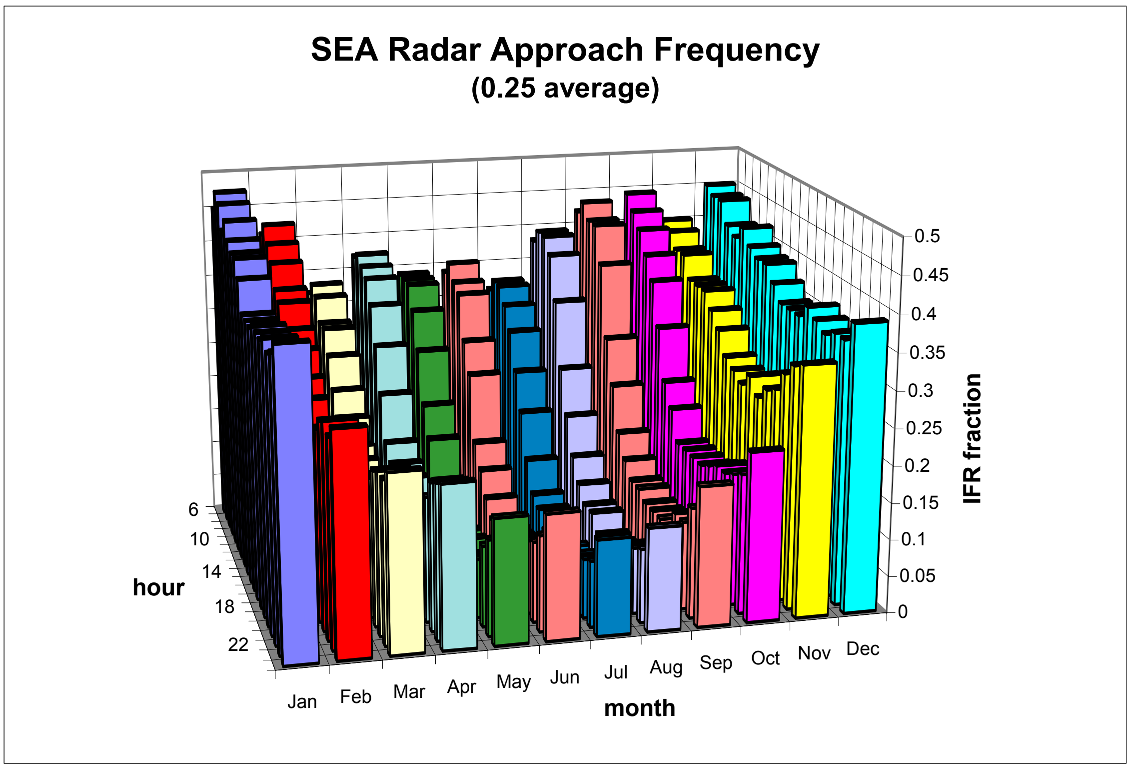


Table B-4. Seattle-Tacoma Meteorological Operating Conditions

Meteorological condition	Ceiling (feet)	Visibility (statute miles)
VFR-1 North flow	c ≥ 3100	v > 7
VFR-1 South flow daylight	c ≥ 3100	v > 4
VFR-1 South flow night	c ≥ 5000	v > 5
VFR-2	2500 ≤ c < VFR-1	3 ≤ v < VFR-1
IFR-1	800 ≤ c < 2500	2 ≤ v < 3
IFR-2	c < 800	v < 2

Figure B-4. Seattle-Tacoma Radar Approach Frequency



Appendix C
Input Parameters

This appendix contains the Current Technology Baseline input parameters used in the capacity and delay models. For the AILS analysis we used three baselines: Current Technology, Passive Final Approach Spacing Tool (PFAST), and Active Final Approach Spacing Tool (AFAST). Both PFAST and AFAST are enhancement technologies to the Center TRACON Automation System (CTAS).

The PFAST baseline differs from the Current Technology Baseline by the reduction of the "inefficiency buffer," $1/\lambda$, from 0.25 nautical mile to 0.1 nautical miles. All other parameters are unchanged.

The AFAST baseline differs from the Current Technology baseline by

- reduction of the inefficiency buffer, $1/\lambda$, from 0.25 nautical miles to 0.05 nautical miles,
- reduction of the position uncertainty, $\sigma_{x,}$ from 0.25 nautical miles to 0.113 nautical miles (100 feet), and
- reduction of speed uncertainty, σ_v, from 5.0 knots to 2.0 knots.

The background for the differences are discussed in Reference 2.

For each technology there is one input file for each of the 4 meteorological conditions. With 4 airports and 3 baselines, 48 input files are required. We also used a generic 4-file set to produce the curves in Chapter 1.

Separate input files are not necessary for AILS cases because the baseline parameters are not changed by AILS. We set a Boolean "AILS" flag in the model command line to instruct the model when to use AILS runway configurations.

In the tables that follow, VMC and IMC (visual meteorological conditions and instrument meteorological conditions) are used instead of VFR and IFR (visual flight rules and instrument flight rules). For the purpose of this study, they are synonymous.

Finally, the input files contain a second separation matrix for AVOSS analysis. In the present case, where AVOSS is not used, the second matrix is set equal to the basic separation matrix.

Generic Case: VFR-1

```
Output file name: c:\airports\ail\ailCTV1.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 1
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  1.9  2.7  3.5  4.5
  1.9  1.9  3.0  3.6
  1.9  1.9  3.0  3.6
  1.9  1.9  2.7  2.7
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.100 0.800 0.050 0.050
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 6.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.667  0.833  0.833  0.917
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.025
Standard deviation of communications delay in minutes
 0.0025
Second (AVOSS) arrival separation matrix in nautical miles:
  1.9  2.7  3.5  4.5
  1.9  1.9  3.0  3.6
  1.9  1.9  3.0  3.6
  1.9  1.9  2.7  2.7
```

Generic Case: VFR-2

```
Output file name: c:\airports\ail\ailCTV2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 2
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  2.5  4.0  5.0  6.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.100 0.800 0.050 0.050
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 6.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.667  0.833  0.833  0.917
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.025
Standard deviation of communications delay in minutes
 0.0025
Second (AVOSS) arrival separation matrix in nautical miles:
  2.5  4.0  5.0  6.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  4.0
```

Generic Case: IFR-1

```
Output file name: c:\airports\ail\ailP1I1.in
Mean of the efficiency buffer distribution
 0.10
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 3
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  2.5  4.0  5.0  6.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.100 0.800 0.050 0.050
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 6.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.667  0.833  0.833  0.917
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Second (AVOSS) arrival separation matrix in nautical miles:
  2.5  4.0  5.0  6.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  4.0
```

Generic Case: IFR-2

```
Output file name: c:\airports\ail\ailCTI2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 4
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.100 0.800 0.050 0.050
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 6.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.800  1.000  1.000  1.100
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

New York, JFK: VFR-1

```
 Output file name: c:\airports\jfk\jfkCTV1.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 1
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  1.9  2.7  3.5  4.5
  1.9  1.9  3.0  3.6
  1.9  1.9  3.0  3.6
  1.9  1.9  2.7  2.7
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.120 0.410 0.050 0.420
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 8.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.750  0.900  0.900  0.983
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   1.0
Communications delay in minutes
  0.025
Standard deviation of communications delay in minutes
 0.0025
Second mix for departures - JFK only
 0.120 0.410 0.050 0.420
Second common path length
 12.0
Second (AVOSS) arrival separation matrix in nautical miles:
  1.9  2.7  3.5  4.5
  1.9  1.9  3.0  3.6
  1.9  1.9  3.0  3.6
  1.9  1.9  2.7  2.7
```

New York, JFK: VFR-2

```
Output file name: c:\airports\jfk\jfkCTV2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 2
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  2.5  4.0  5.0  6.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.120 0.410 0.050 0.420
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 8.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.750  0.900  0.900  0.983
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   5.0
Communications delay in minutes
  0.025
Standard deviation of communications delay in minutes
 0.0025
Second mix for departures - JFK only
 0.120 0.410 0.050 0.420
Second common path length
 12.0
Second (AVOSS) arrival separation matrix in nautical miles:
  2.5  4.0  5.0  6.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  4.0
```

New York, JFK: IFR-1

```
Output file name: c:\airports\jfk\jfkCTI1.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 3
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.120 0.410 0.050 0.420
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 8.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.750  0.900  0.900  0.983
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   5.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Second mix for departures - JFK only
 0.120 0.410 0.050 0.420
Second common path length
 12.0
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

New York, JFK: IFR-2

```
Output file name: c:\airports\jfk\jfkCTI2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 4
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.120 0.410 0.050 0.420
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 8.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.900  1.080  1.080  1.180
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   5.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Second mix for departures - JFK only
 0.120 0.410 0.050 0.420
Second common path length
 12.0
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

Detroit, DTW: VFR-1

```
Output file name: c:\airports\dtw\dtwCTV1.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 1
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  1.9  2.7  3.5  4.5
  1.9  1.9  3.0  3.6
  1.9  1.9  3.0  3.6
  1.9  1.9  2.7  2.7
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.110 0.780 0.060 0.050
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 6.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.617  0.833  0.833  0.933
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.025
Standard deviation of communications delay in minutes
 0.0025
Second (AVOSS) arrival separation matrix in nautical miles:
  1.9  2.7  3.5  4.5
  1.9  1.9  3.0  3.6
  1.9  1.9  3.0  3.6
  1.9  1.9  2.7  2.7
```

Detroit, DFW: VFR-2

```
Output file name: c:\airports\dtw\dtwCTV2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 2
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  2.5  4.0  5.0  6.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.110 0.780 0.060 0.050
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 6.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.617  0.833  0.833  0.933
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.025
Standard deviation of communications delay in minutes
 0.0025
Second (AVOSS) arrival separation matrix in nautical miles:
  2.5  4.0  5.0  6.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  4.0
```

Detroit, DTW: IFR-1

```
Output file name: c:\airports\dtw\dtwCTI1.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 3
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.110 0.780 0.060 0.050
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 6.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.617  0.833  0.833  0.933
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

Detroit, DTW: IFR-2

```
Output file name: c:\airports\dtw\dtwCTI2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 4
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.110 0.780 0.060 0.050
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 6.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.740  1.000  1.000  1.120
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

Minneapolis-St. Paul, MSP: VFR-1

```
Output file name: c:\airports\dtw\dtwCTI2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 4
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.110 0.780 0.060 0.050
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 6.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.740  1.000  1.000  1.120
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

Minneapolis-St. Paul, MSP: VFR-2

```
Output file name: c:\airports\dtw\dtwCTI2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 4
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.110 0.780 0.060 0.050
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 6.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.740  1.000  1.000  1.120
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

Minneapolis-St.-Paul, MSP: IFR-1

```
Output file name: c:\airports\msp\mspCTI1.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 3
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.130 0.750 0.080 0.040
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 5.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.700  0.767  0.767  0.817
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Number of enqueued aircraft tracked for closely spaced parallel
runways
  6
MSP Runway 30 ROTs (the first set is Runway 12
  0.700  0.850  0.850  0.950
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

Minneapolis-St.Paul, MSP: IFR-2

```
Output file name: c:\airports\msp\mspCTI2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 4
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.130 0.750 0.080 0.040
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 5.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.840  0.920  0.920  0.980
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   3.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Number of enqueued aircraft tracked for closely spaced parallel
runways
  6
MSP Runway 30 ROTs (the first set is Runway 12
  0.840  1.020  1.020  1.140
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

Seattle-Tacoma, SEA: VFR-1

```
Output file name: c:\airports\sea\seaCTV1.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 1
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  1.9  2.7  3.5  4.5
  1.9  1.9  3.0  3.6
  1.9  1.9  3.0  3.6
  1.9  1.9  2.7  2.7
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.210 0.650 0.060 0.080
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 5.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.717  0.800  0.800  0.833
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   5.0
Communications delay in minutes
  0.025
Standard deviation of communications delay in minutes
 0.0025
Number of enqueued aircraft tracked for closely spaced parallel runways
  6
SEA Runway 16L & 34R ROTs (the first set is new & center
  0.733  0.833  0.833  1.000
TIME_TO_CROSS the active runway
 0.50
Distance to departure turn for north flow
  6.5
ILS holdline delays for 16L and 34R in IMC2
 0.75 0.80
Second (AVOSS) arrival separation matrix in nautical miles:
  1.9  2.7  3.5  4.5
  1.9  1.9  3.0  3.6
  1.9  1.9  3.0  3.6
  1.9  1.9  2.7  2.7
```

Seattle-Tacoma, SEA: VFR-2

```
Output file name: c:\airports\sea\seaCTV2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 2
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  2.5  4.0  5.0  6.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.210 0.650 0.060 0.080
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 5.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.717  0.800  0.800  0.833
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   5.0
Communications delay in minutes
  0.025
Standard deviation of communications delay in minutes
 0.0025
Number of enqueued aircraft tracked for closely spaced parallel runways
  6
SEA Runway 16L & 34R ROTs (the first set is new & center
  0.733  0.833  0.833  1.000
TIME_TO_CROSS the active runway
 0.50
Distance to departure turn for north flow
  6.5
ILS holdline delays for 16L and 34R in IMC2
 0.75 0.80
Second (AVOSS) arrival separation matrix in nautical miles:
  2.5  4.0  5.0  6.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  5.0
  2.5  2.5  4.0  4.0
```

Seattle-Tacoma, SEA: IFR-1

```
Output file name: c:\airports\sea\seaCTI1.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 3
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.210 0.650 0.060 0.080
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 5.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.717  0.800  0.800  0.833
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   5.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Number of enqueued aircraft tracked for closely spaced parallel runways
  6
SEA Runway 16L & 34R ROTs (the first set is new & center
  0.733  0.833  0.833  1.000
TIME_TO_CROSS the active runway
 0.50
Distance to departure turn for north flow
  6.5
ILS holdline delays for 16L and 34R in IMC2
 0.75 0.80
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

Seattle-Tacoma, SEA: IFR-2

```
Output file name: c:\airports\sea\seaCTI2.in
Mean of the efficiency buffer distribution
 0.25
Meteorological condition: 1=VMC1, 2=VMC2, 3=IMC1, 4=IMC2
 4
Number of aircraft classes in separation matrix
 4
First (basic) arrival separation matrix in nautical miles
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
Flag indicating heavy class aircraft for departure calculations
   0   0   1   1
Aircraft mix: small, large, B757, heavy
 0.210 0.650 0.060 0.080
Average approach speed over common path in knots
 135.0 140.0 140.0 145.0
Standard Deviation of approach speed in knots
  5.0  5.0  5.0  5.0
Standard deviation of position uncertainty in nautical miles
 0.25 0.25 0.25 0.25
Common path length in nautical miles
 5.0
Standard deviation of wind speed in knots
 7.5
Arrival runway occupancy times in minutes
  0.860  0.960  0.960  1.000
Standard deviation of arrival runway occupancy time in minutes
  0.130  0.130  0.130  0.130
Departure runway occupancy time in minutes
  0.500  0.667  0.667  0.667
Standard deviation of departure runway occupancy time in minutes
  0.100  0.100  0.100  0.100
Departure speed in knots
  130.0  180.0  180.0  180.0
Standard deviation of departure speed in knots
   5.0   5.0   5.0   5.0
Distance to departure turn in nautical miles
   5.0
Communications delay in minutes
  0.100
Standard deviation of communications delay in minutes
 0.0100
Number of enqueued aircraft tracked for closely spaced parallel runways
  6
SEA Runway 16L & 34R ROTs (the first set is new & center
  0.880  1.000  1.000  1.200
TIME_TO_CROSS the active runway
 0.50
Distance to departure turn for north flow
  6.5
ILS holdline delays for 16L and 34R in IMC2
 0.75 0.80
Second (AVOSS) arrival separation matrix in nautical miles:
  3.0  4.0  5.0  6.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  5.0
  3.0  3.0  4.0  4.0
```

Appendix D
AILS Lifecycle Cost Analysis and Benefit-to-Cost Comparison

This appendix documents a preliminary lifecycle cost and cost-to-benefit for a "basic" AILS configuration. Aircraft display modifications are minimal; the system provides automatic alert, warning, and evasion queues on the navigation display when blunders are detected. All hardware is commercial off-the-shelf (COTS) and no hardware development is required. NASA has demonstrated that the basic configuration allows safe independent approaches to parallel runways separated by at least 2,500 feet.

In accordance with normal practice, all prior NASA research and development costs are considered sunk. We have not estimated any FAA test and certification costs. Such costs should be added to the estimate in the future.

Technical content of the basic AILS are based on discussions with Bill Corwin of Honeywell and Terry Abbott or NASA Langley Research Center (LaRC). Cost factors, labor rates, quantities, and other economic data are taken from our previous TAP technology estimates.

TECHNICAL CONTENT

The required hardware includes:

- a Multi-Mode Receiver (MMR) that includes Instrument Landing System (ILS) and Differential Global Positioning System (DGPS) capability,
- a Mode-S transponder with a level 3-4 (56-bit message) automatic dependent surveillance—broadcast (ADS-B) capability,
- new wiring from the Traffic Alert and Collision Avoidance System (TCAS) to the MMR—estimated to be a single twisted pair.

The required software includes:

- additional TCAS software to detect blunders and display alerts,
- additional FMS software to document airport data necessary for AILS "skewed localizer" arrival profiles.

ASSUMPTIONS

Multi-Mode Receiver (MMR): The MMR is an off-the-shelf navigation receiver. An MMR includes multiple circuit card slots that allow use of ILS, GPS, and Microwave Landing System (MLS) cards. Many aircraft are currently equipped with MMRs. Aircraft flying to Europe today typically have ILS and MLS cards. We assume DGPS cards will be installed in all existing MMRs by 2005. Some fraction of the fleet will still have conventional radios and will need new MMRs in 2005. We assume a total fleet of 6200 (based on our previous work) and further assume that 20 percent of the fleet will need new radios, resulting in a requirement for 1,240 radios in 2005.[1] We further assume that all new aircraft built after 2005 have MMRs with DGPS capability as basic equipment for purposes other than AILS. We use $30,000 for the acquisition price of an MMR.[2]

Multi-Mode Receiver Assumption Summary

- 20 percent of 6,200 aircraft will require radios
- Post-2005 aircraft come equipped with MMR
- $30,000 per radio acquisition price
- Form, fit, and function replacement of existing radio
- 5 percent spares
- 1 hour installation time
- 1 hour aircraft out-of-service time for installation
- no additional maintenance cost because the MMR is replacing a current radio with the same maintenance burden

Mode-S Transponders: The current AILS implementation includes a Mode-S level 3-4 (56-bit message) transponder. The transponder operates in an automatic dependent surveillance–broadcast (ADS-B) mode. Recent FAA sponsored ADS-B tests have been very successful.[3] Both Mode-S Extended Squitter and Universal Access Transceiver (UAT) data links were used for the tests, and the VHF Data Link Mode-4 (VDLM4) will be tested in the future. Should ADS-B be adopted, which we feel is a safe assumption, one of these data links will become ubiqui-

[1] 6,200 is the 2005 estimate for all the airlines servicing the 10 airports analyzed in the TAP study.

[2] $30,000 was the value for a digital data radio used in our previous work. The value was based on information from Rockwell Collins for and on FAA estimates. Bill Corwin did not think the amount was out of line for the MMR.

[3] "ADS-B proves Successful in Aircraft Separation Test," James Ott, *Aviation Week & Space Technology,* September 27, 1999 (p.50).

tous. We also note that new Mode-S transponders from both Collins and Honeywell are advertised to have growth capacity to support extended messages. Consequently, we assume no new data links will be required for AILS.

New wiring is required from the MMR to the TCAS (computer). New wiring is assumed to include a single twisted pair ARINC 429 data bus. No modifications to the TCAS or MMR boxes are required. The wiring is assumed to be installed during normal inspection and overhaul and only a *pro rata* share of aircraft downtime is charged to the modification.

New Wiring Assumptions Summary

- One cable per aircraft for 6200 existing aircraft
- Post-2005 aircraft come wired
- $200 per cable acquisition cost, including installation documentation
- One design and installation plan for each of 4 vendors
- $10,000 per vendor for engineering
- $5,000 per vendor for installation documentation
- 15-year lifetime
- 10 percent spares
- $0 for maintenance
- 1-hour installation
- 30 minutes aircraft out-of-service time

TCAS Software: Honeywell estimated the TCAS software requirement in the "hundreds of lines of code" range. NASA Langley agreed with that estimate, as did an engineer from Rockwell Collins.[4] We assume 800 lines of code for our estimate. We assume that four vendors will independently develop software for their TCAS equipment. The development is low risk since the NASA program has developed flight-proven software in the AILS program. We do not include a per airplane charge for the software.

Flight Management System (FMS) Software: New FMS software is required to implement the skewed localizer technique used by both Honeywell and NASA. The use of the NASA "rocket ship" approach profile is a long-term future option. The software is assumed to be a small subset of approach data software currently

[4] telecons: 13 Oct 99 with Bill Corwin of Honeywell, 14 Oct 99 with Terry Abbott of LaRC, and 19 Oct 99 with Steve Koczo of Rockwell Collins.

maintained in FMSs. Based on the number of major airports having or planning parallel runway configurations with separations from 2,500 to 4,300 feet, FMS data will be required for, at most, 10 to 20 runway pairs.[5] We assume 1,000 lines of additional code will be required.

Software Assumptions Summary

- 800 TCAS system lines of code
- 1,000 FMS system lines of code
- Four avionics suppliers independently develop one version of software each.

Training: Training is relatively minimal. Terry Abbott of LaRC suggested that the airlines would probably provide written information and maybe a video to its pilots, plus about 10 minutes of first-time and recurring simulator training. We assume that 4 two-person aircrews are required for each of the 6,200 aircraft in the fleet. These crews would be trained once in 2005. Recurring annual training is based on a 20 percent turnover rate.

Training Assumptions Summary

- Training consists of 10 minutes of simulator
- 2 crewmembers per crew
- 4 crews per aircraft
- 20 percent annual crew turnover.

ESTIMATING METHODOLOGIES

We estimate the MMR and the wiring with a modified ARINC Cost-of-Ownership Model. The model is basically an organized accounting system to insure all appropriate costs are recognized and included. We have implemented the model on a spreadsheet and added cost categories and alternate algorithms as needed. Typical model inputs include acquisition costs, quantities, installation hours and materials, support equipment costs, maintenance hours and materials, initial and recurring training hours, labor rates, and others. The output includes initial non-recurring costs and annual recurring ownership costs. The basic ARINC model has an algorithm for estimating annual costs which we do not use.

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[5] references: "Parallel Runway Pairs in the Top 100 Airports," vu-graph slide in *the Proceedings of the NASA Workshop on Flight Deck Centered Parallel Runway Approaches in Instrument Meteorological Conditions*, NASA Conf. Pub. 10191, Waller and Scanlon, Dec 1996, *and Air Traffic and Operational Data on Selected U.S. Airports with Parallel Runways*, NASA/CR-1998-207675, Doyle and McGee, May 1998.

Instead, we calculate annual charges for the system lifecycle on a separate spreadsheet.

We annualize the initial hardware investments using an Effective Annual Charge (EAC) based on the base year, hardware service life, and the discount rate. The EAC is a financial technique used to compare investments with different service lives. In our case, we are interested in the 10-year lifecycle costs (2006-1015) for hardware having estimated service lives of 15 years. Mathematically, the EAC is the same as a mortgage calculation with an interest rate equal to the discount rate and a period equal to the service life. Thus, it also compares closely with the cash flow required for financed hardware. Annual recurring costs such as maintenance are directly charged in the year they occur.

Software costs are estimated based on system lines of code (SLOC) using the Revised Intermediate Constructive Cost (COCOMO) Model (REVIC). REVIC is an Air Force model with factors based on an avionics data base. The results compare well with simple estimates based on both FAA and commercial software productivity factors. Four vendors are assumed to conduct parallel software developments. All software costs are directly charged in the year they occur.

Training: Training is estimated using the training sections of the modified ARINC Cost of Ownership model. The model includes direct charges for simulator training and indirect charges for pilot non-availability.

RESULTS

The models generate non-recurring and annual recurring estimates in constant dollars. As discussed above, we spread the non-recurring hardware costs over the 10 years from 2006-2015 using the equivalent annual charge method. Initial training costs are charged in 2005. Recurring hardware, training, and software maintenance costs are charged to the years in which they occur. For benefit to cost comparisons, we convert the constant dollar to present value (discounted) dollars using the FAA/OMB recommended 7 percent discount rate and a 1997 base year. For budgeting purposes we escalate the constant dollar results to “Then Year” or “Budget” using a 2.6 percent inflation rate. The 10-year lifecycle results are shown in the Table D-1.

Table D-1. A ILS 2005-2016 10-Year Lifecycle Cost Summary (In Millions)

Estimated component	Quantity assumptions	1997 constant dollars	Present value dollars	Then year dollars
Multimode rreceiver	(1240 aircraft)	45.1	18.4	64.0
TCAS-to-FMS cable	(6200 aircraft)	4.9	2.0	6.9
AILS training	(148,800 training sessions)	11.4	5.6	15.1
TCAS software	(4 vendors)	0.3	0.2	0.4
FMS software	(4 vendors)	0.4	0.2	0.6
Total		62.2	26.4	87.0

The total estimated benefits for AILS deployment at JFK, MSP, DTW, and SEA are shown in Table D-2. As discussed in Chapter 1, the VOC-fuel+FA (variable operating cost per minute minus fuel plus flight attendants - $25.69) and DOC (direct operating per minute plus flight attendants - $46.79) represent lower and upper bounds of the benefit estimate. Recall from Chapter 1 that the benefits are based on the difference between estimated arrival delay for each of three future baselines is compared to the delay for those baselines with AILS technology.

Table D-2. AILS Benefits (Arrival Delay Savings)

Scenario	Minutes in millions	1997 Constant $ in millions			Present Value $ in millions		
		VOC - fuel +FA	DOC+ FA	Average	VOC- fuel +FA	DOC+ FA	Average
Current Technology with AILS	15.3	393	715	554	150	272	211
PFAST with AILS	13.0	333	607	470	127	231	179
AFAST with AILS	7.4	189	345	267	72	131	102

Table D-3 shows the present value benefit-to-cost ratios based on the average present value of the benefits. The table shows that AILS produces benefit-to-cost ratios well above 1.0 even though the benefits are based on only four airports and the costs are based on the whole fleet.

Table D-3. Cost Benefit Ratios

Baseline scenario	Present Value of benefits in millions	Present value of costs in millions	Net Present Value in millions	Benefit to cost ratio
Current Technology	211	26.4	185	8.0
PFAST	179	26.4	153	6.8
AFAST	102	26.4	76	3.9

ESTIMATE CAVEATS

Several issues should be considered when interpreting the cost and benefit information. These include:

Multi-Mode Receiver Cost Assignment: The MMR provides benefits other than AILS and part of the cost of the MMR should undoubtedly be apportioned to other programs.

Fleet Size: Costs based on the 6200 aircraft fleet should cover not just the four airports studied, but also a significant fraction of the top 100 U.S. airports. Far fewer aircraft would need to be equipped to serve the three airports (DTW, MSP, and SEA) that provide the bulk of the estimated benefits.

Preliminary Nature of Cost Estimates: The cost estimates contained in this report are preliminary and have not been critically reviewed for either completeness or methodology. Several of the assumptions are based on educated guesses, including the lines of code estimate for the FMS, the wiring costs, the number of aircraft requiring MMRs, and the assumed existence in 2005 of adequate Mode-S or alternative data links.

FAA Acceptance: As noted above, we have not estimated costs for FAA testing and certification. Since AILS places safe separation responsibility on the pilot, we assume that extensive air traffic controller training will not be required. We note, however, that AILS implementation will require a major revision of controller/pilot responsibilities in the terminal airspace and significant (and costly) testing may be required to gain acceptance of AILS by controllers and pilots.

Technical Content: Our estimate is based on the technical content of the NASA and Honeywell AILS demonstrators. An operational AILS system may be classified a “high integrity” system like ILS. For high integrity, the operational AILS system may need redundant equipment and/or communications and software integration with other back-up systems. Note that neither TCAS nor FMS are currently high integrity systems. Relatively low cost approaches such as the Receive Automated Integrity Monitoring (RAIM) used for GPS systems may be applicable.

CONCLUSION

Subject to the analysis limitations discussed above, the Net Present Values, based on the preliminary cost estimates and the 4 airports, indicate that AILS benefits should be adequate to justify continued development and implementation.

Appendix E
Capacity and Delay Charts

Late in the study NASA requested that capacity charts be constructed similar to the arrival delay chart appearing in the Executive Summary. The charts are contained in this appendix. Also included are arrival delay charts for all the technology baselines. Before presenting the capacity charts, it is important to discuss what they represent.

There is no *single* answer to the question, “What is the capacity of a runway configuration?” As discussed in the main body of the report, the capacity of a runway configuration is defined by a unique *arrival/departure trade-off curve*. The capacity of the configuration depends on the selected arrival/departure ratio. For each runway configuration at an airport there are separate curves for each technology level and meteorological condition. One *can* answer the question, “What are the arrival and departure capacities of a runway configuration using technology ‘X’ in meteorological condition ‘Y,’ when operated at a departure-to-arrival ratio ‘Z’?” Such answers are vital to tactical decisions and modeling, but are of little value for describing strategic benefits.

We believe integrated airport arrival capacity is most appropriate for describing AILS strategic benefits. By integrated data we mean the average airport arrival capacities experienced over a period of time with a particular technology during selected meteorological conditions. Specifically, we compare the average hourly arrival capacities taken over all airport operating hours and all weather data years for the following parameters:[1]

- Technology Baseline: Current Technology, PFAST, and AFAST
- Technology: No AILS, AILS
- Meteorological Operating Condition: Radar approach conditions and Visual approach conditions
- Demand Year: 2005 and 2015.

[1] Airport operating hours are airport specific and are typically 0600 to 2300.

Weather years span from 1961 to 1995 for DTW and JFK (35 years), 1961-1990 for MSP (30 years), and 1961-1990 with 3 bad data years removed for SEA (27 years).

In practice, for a given airport, we run the capacity models once for each airport technology baseline (CT, PFAST, AFAST)/TAP technology (no AILS, AILS) combination (i.e., 24 times). We run the delay model once for each airport, technology baseline/TAP technology combination, and demand year (2005, 2015) (i.e., 48 times). As described in Chapter 1, the delay model emulates the behavior of the traffic management unit. For each hour the model checks the ceiling and visibility to determine the appropriate meteorological condition, checks the wind speed and direction to determine the legal runways, checks the scheduled departure and arrival demand for the current hour and the residual demand from the previous hour. The arrival/departure demand ratio is used to select the operating point on the arrival/departure trade-off curve and all available configurations are checked to select the configuration with the best capacity. The resulting arrival and departure capacities and the arrival and departure demands are sent to the queuing routine which calculates the current hour's arrival and departure delays any residual demand for the next hour. For capacity data analysis, we accumulate the scheduled demands and capacities for visual and radar meteorological conditions, and calculate average capacities.

Two factors must be kept in mind when interpreting the capacity charts. The first is that arrival capacities are for the *entire airport*, based on the mix of configurations selected by the delay model. For the JFK chart in particular, AILS and non-AILS radar capacities show little change because the AILS-affected runways are rarely used and airport capacity is dominated by configurations that are not AILS-affected.

The second factor is that capacities can vary with demand year because the hourly demands upon which the capacities are based change with demand year. As noted above, the hourly demand includes both the scheduled demand and the residual demand left over from the previous hour. The residual demand is generated by the queuing engine and is a function of both technology (available capacity) and the size of the scheduled demand (higher scheduled demand results in more delays and, thus, higher residual demand). Since the arrival/departure operating points on the capacity curves are dependent on the scheduled demand plus the residual demand, the hourly capacities can differ for the same technologies for different demand years. For example, if arrival demand increases and capacity is limited, more residual arrivals will be added to the demand and the runways will be operated at arrival heavy operating points. Such changes are noticeable in the Minneapolis-St. Paul (MSP) charts where the 2015 arrival capacities for both visual and radar conditions are higher than corresponding 2005 arrival capacities. The differences are due to differences in the operating points, not in technology.

Figures E-1 through E-12 compare the "Visual," "Radar with AILS," and "Baseline Radar" capacities for the 4 airports and 3 technology baselines. Note that "Visual" means visual approaches and implies VFR-1 conditions except at Seattle-Tacoma (SEA) where it also includes VFR-2. "Radar" means radar controlled approaches and includes VFR-2, IFR-1, and IFR-2 conditions except at SEA where it only includes IFR-1 and IFR-2.

Figures E-13 through E-15 compare the average minutes per flight of arrival delay at each airport with and without AILS for each technology baseline. The chart for the Current Technology baseline is also contained in Executive Summary. Delay is a more straightforward measurement than capacity and is directly related to costs and savings.

Both the capacity and delay charts indicate that AILS should make a significant contribution toward the TAP goal of maintaining good weather operating capability in bad weather conditions.

Figure E–1. Detroit (DTW) Arrival Capacity With Baseline Technology

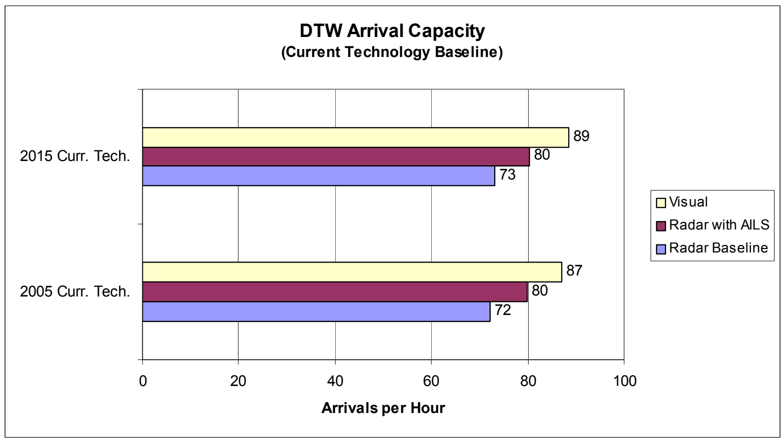


Figure E–2. Detroit (DTW) Arrival Capacity With PFAST Baseline

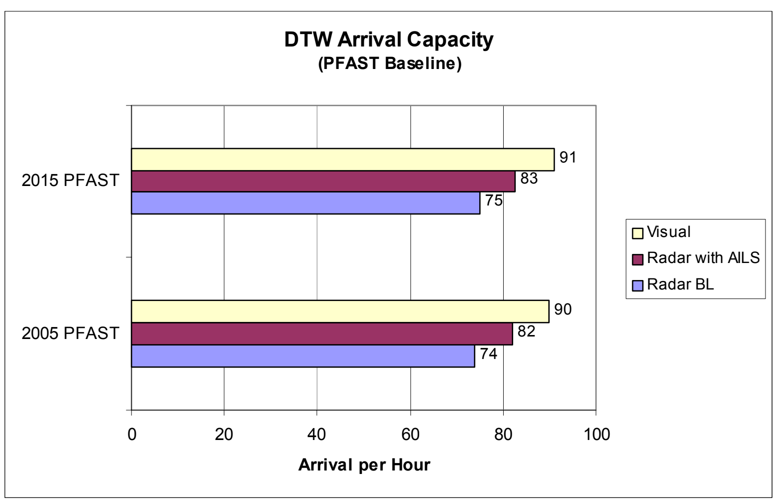


Figure E–3. Detroit Arrival CapacityWith AFAST Baseline

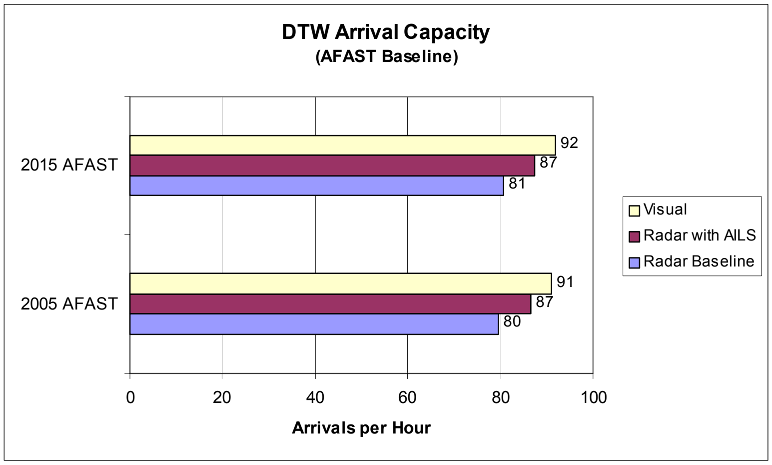


Figure E–4. New York Kennedy (JFK) Arrival Capacity With Current Technology Baseline

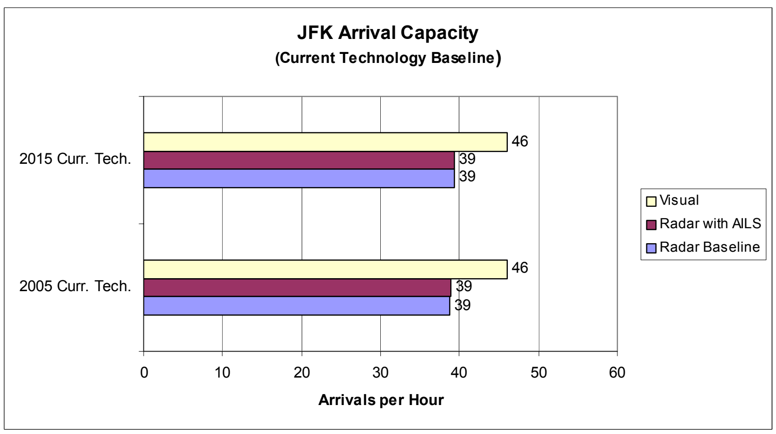


Figure E–5. New York Kennedy (JFK) Arrival Capacity With PFAST Baseline

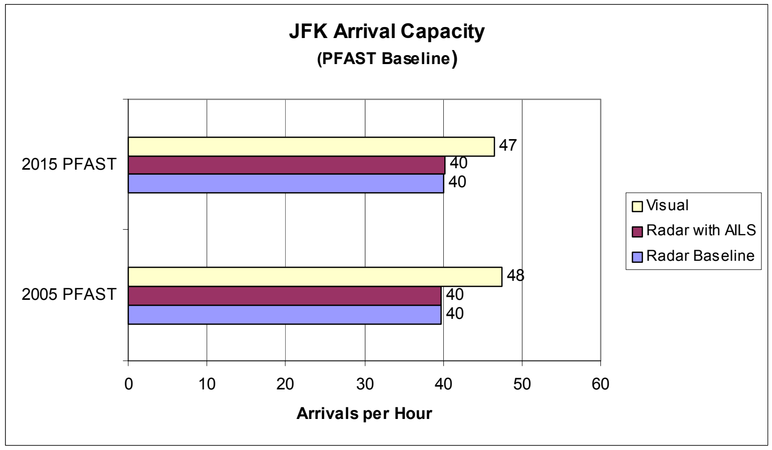


Figure E–6. New York Kennedy (JFK) Arrival Capacity with AFAST Baseline

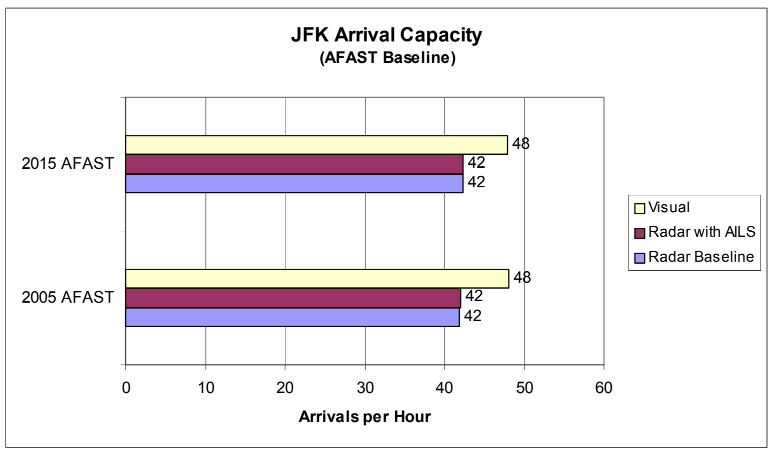


Figure E–7. Minneapolis-St. Paul (MSP) Arrival Capacity With Current Technology Baseline

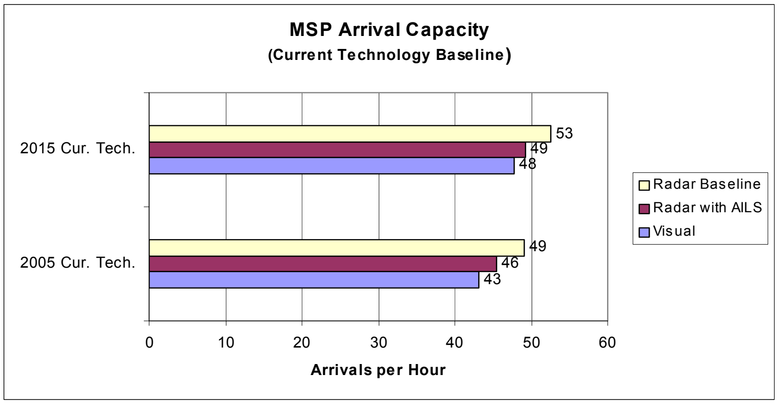


Figure E–8. Minneapolis-St. Paul (MSP) Arrival Capacity With PFAST Baseline

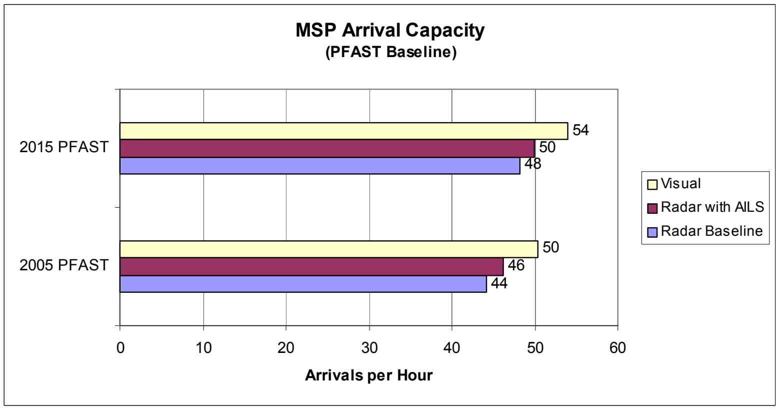


Figure E–9. Minneapolis-St. Paul (MSP) Arrival Capacity With AFAST Baseline

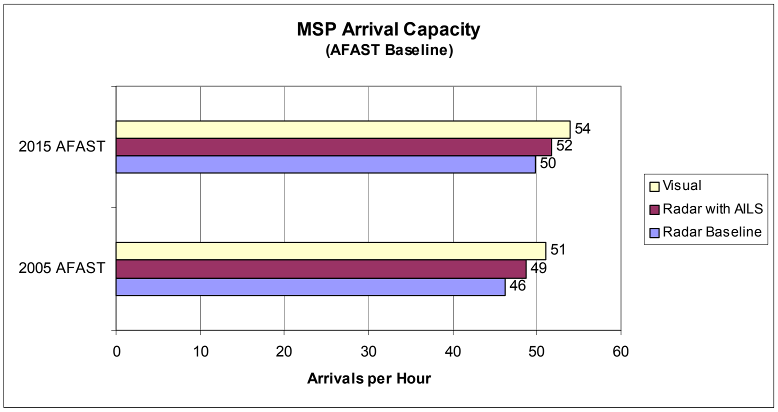


*Figure E–10. Seattle-Tacoma (SEA) Arrival Capacity
With Current Technology Baseline*

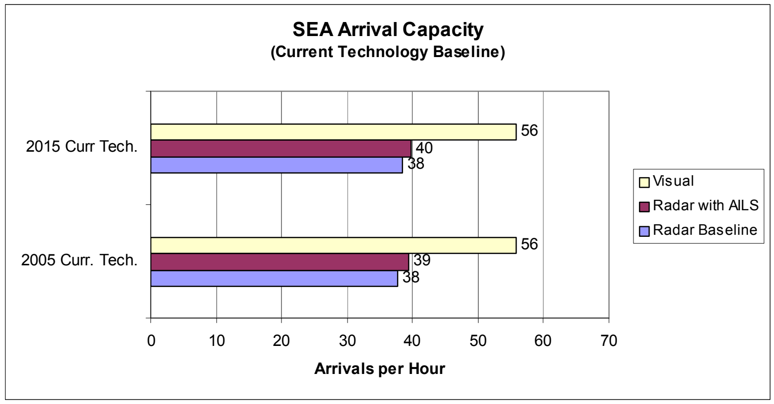


Figure E–11. Seattle-Tacoma (SEA) Arrival Capacity With PFAST Baseline

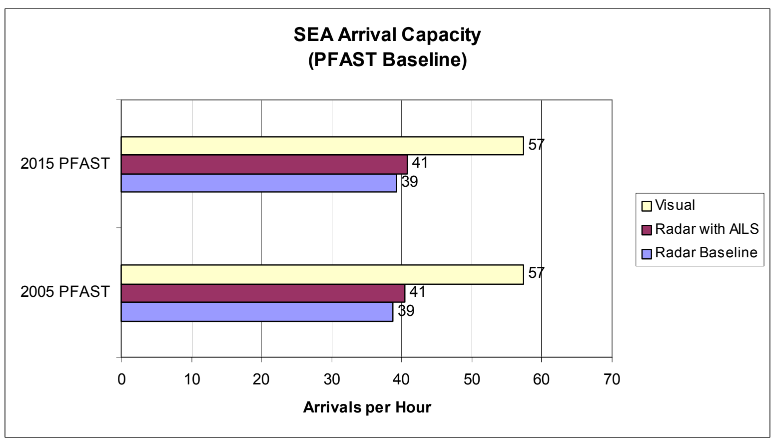


Figure E–12. Seattle-Tacoma (SEA) Arrival Capacity with AFAST Baseline

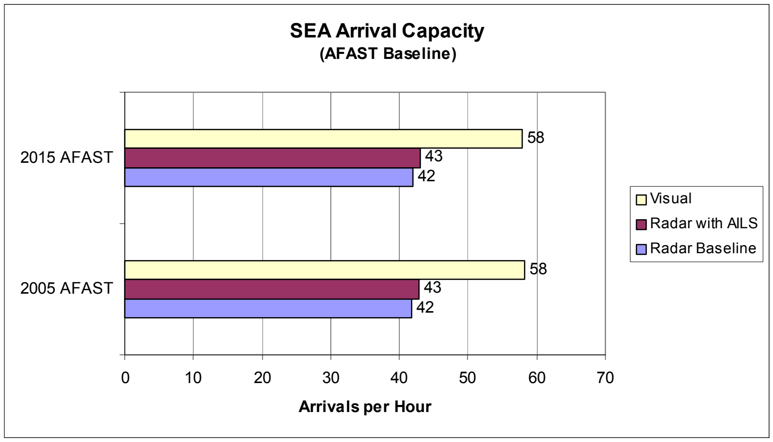


Figure E–13. Delay Summary with Current Technology Baseline

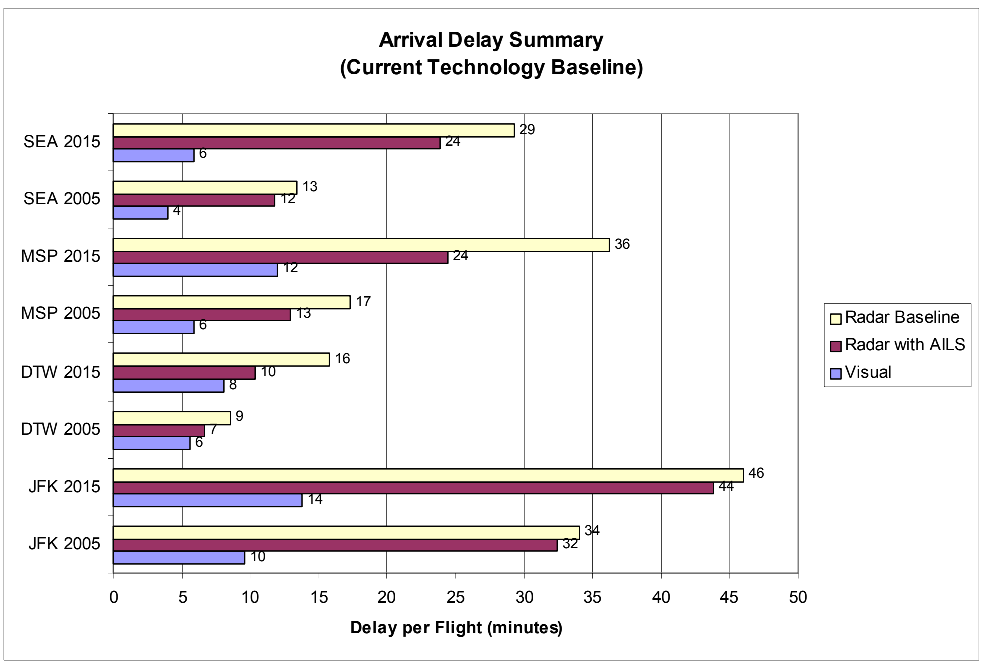


Figure E–14. Arrival Delay Summary with PFAST Baseline

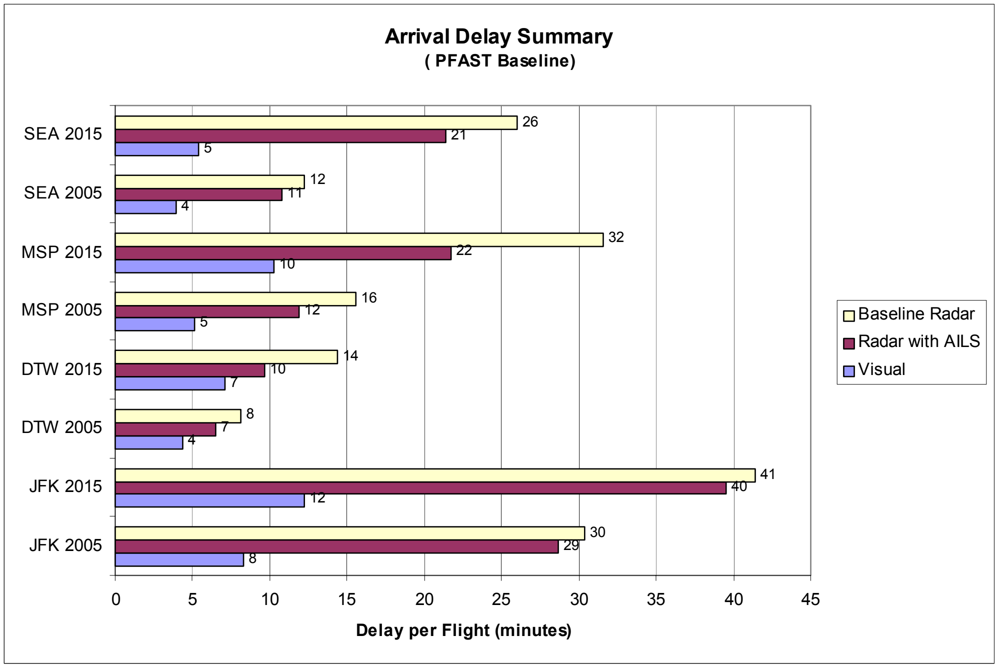
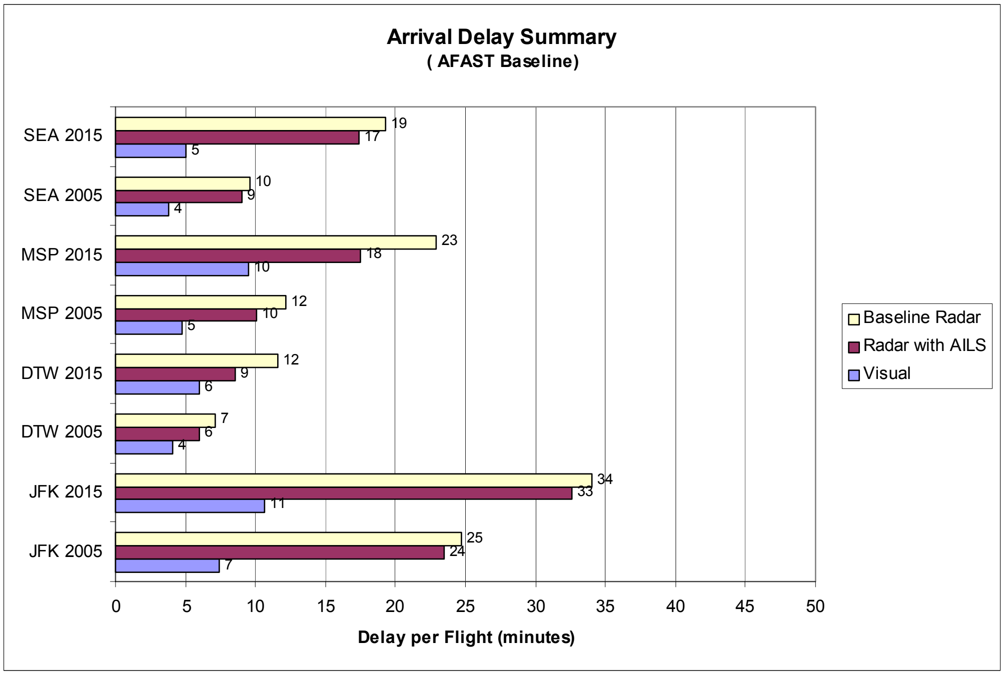


Figure E–15. Arrival Delay Summary for AFAST Baseline



Appendix F
Abbreviations

AFAST	Active Final Approach Spacing Tool
AILS	Airborne Infoprmation for Lateral Spacing
ARINC	Aeronautical Radio, Incorporated
AVOSS	Aircraft Vortex Spacing System
BFI	Boeing Field Airport
COTS	Commercial Off-the-Shelf
CTAS	Center-TRACON Automation System
DFW	Dallas-Ft Worth Airport
DGPS	Differential Global Positioning Satellite
DOC	direct operating cost
DTW	Detroit Wayne County Airport
EAC	equivalent annual charge
FAA	Federal Aviation Administration
FMS	flight management system
GPS	global positioning satellite
IAT	Inter-arrival Time
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	instrument meteorological conditions
JFK	New York John F. Kennedy Airport
MC	meteorological condition

MLS	Microwave Landing System
MMR	Multi-mode Receiver
MSP	Minneapolis-St. Paul Airport
NASA	National Aeronautics and Space Administration
OAG	Official Airline Guide
ORD	Chicago O'Hare Airport
PFAST	Passive Final Approach Spacing Tool
PRM	Precision Runway Monitor
REVIC	Revised Intermediate COCOMO
ROT	runway occupancy time
SEA	Seattle-Tacoma Airport
SLOC	System Lines of Code
TAF	terminal area forecast
TAP	terminal area productivity
TCAS	Traffic Alert and Collision Avoidance System
TRACON	Terminal Radar Approach Control
UAT	Universal Access Transceiver
VDLM4	VHF Data Link Mode 4
VFR	visual flight rules
VHF	very high frequency
VMC	visual meteorological conditions
VOC	variable operating costs

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13. ABSTRACT *(Maximum 200 words)*

The Logistics Management Institute, under contract to NASA, has estimated the reduction in arrival delay that can be expected for AILS systems implemented at New York Kennedy (JFK), Detroit Wayne County (DTW), Minneapolis-St. Paul (MSP), and Seattle-Tacoma (SEA). Benefits are based on the minutes of arrival delay saved by the AILS technologies at these four airports over a 10-year period from 2006 through 2015. The benefits were estimated using detailed airport capacity and delay models for each of the four airports. Benefits were based on the difference between delays with AILS and those from three technology baselines that have been defined in previous NASA Terminal Area Productivity (TAP) analyses. The three baselines include a Current Technology baseline (CT), a Passive Final Approach Spacing Tool baseline (PFAST), and an Active Final Approach Spacing Tool baseline (AFAST). PFAST and AFAST are enhanced variants of NASA's Center TRACON Automation System (CTAS). The Logistics Management Institute also made a preliminary estimate of AILS costs based on the hardware and software ensemble used in the NASA flight tests. The estimate covered navigation receivers, new wiring, aircrew training, and software for the Traffic Alert and Collision Avoidance System (TCAS) and the Flight Management System (FMS). Net Present Values, based on preliminary cost estimates and the 4 airports, indicate that AILS benefits should be adequate to justify implementation.

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